THE HUMAN MACHINE

HOW TO PREVENT BREAKDOWNS

R.L. BIJLANI
S.K. MANCHANDA

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Popular Science

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FOREWORD

Health is a positive state of physical and mental well-being and not merely absence of disease. It would be evident to any person who has studied Medicine, that human machine is the most ingeniously devised, designed and constructed mechanism that exists in the universe. It has such ingenious systems of checks and balances and mechanisms which help preserve a state of normality in whatever environment the human body is placed and whatever provocations it is subjected to. As medical knowledge advances, we learn more and more of the mysteries of the structure and metabolic processes which contribute to the state of positive health and defend the body against disease. Intricacies of these mechanisms are hard to understand fully even for a medical student.

Each one of us have our own notions about the functioning of our bodies, the effect of different kinds of diets and climate on our systems which are based not on any facts but on what we have heard others say. There is acute paucity or near absence of any published material in layman's language which provides correct knowledge to a layman about the complex human organism.

Dr. Bijlani and Dr. Manchanda have done a remarkable job in this work to put across for the layman, knowledge of the human machine in a language that every one can understand. The simple but ingeniously designed diagrams supplement the understanding. I am sure that this work has filled a lacuna and every reader will find the experience of going through this book as most rewarding.

H. D. Tandon
MD, FAMS FRC PATH (LONDON)
Director
ALL INDIA INSTITUTE OF MEDICAL SCIENCES

New Delhi
Nov. 11, 1982

PREFACE

At the outset, we would like to share with the reader the genesis of this book. It was in 1974 that the International Congress of Physiological Sciences was held in New Delhi. This conference was perhaps the first international meeting on a medical subject to be organised in India. It naturally evoked immense interest among journalists. The coverage that many discussions held at the conference received in the lay press created a general awareness about physiology as an important medical science. As a sequel to this publicity, we were invited by a popular Hindi weekly to contribute some articles on physiological subjects. We wrote about a dozen articles, which were translated into Hindi by a science journalist and published in this weekly in 1975. The articles were highly appreciated, and we felt tempted to add more articles to it to complete the journey through the body and compile them all in the form of a book. However, several obstacles delayed the fulfilment of this seemingly simple dream. We are pleased that at last we have been able to offer you this low-priced volume.

Physiology is not merely a medical discipline. It is the science dealing with the normal function of all living organisms, plants as well as animals. But in this volume we shall talk only of animal physiology, mainly human physiology, and that too primarily from the point of view of its application to health and disease. Although physiology deals with only normal function, it has a great role in understanding disease. It is only after normal function has been learnt that deviations from normal, called disease, can be understood. The science of normal health and that of ill health are just as inseparable as the science of good weather and that of bad weather. A few examples would illustrate the relationship.

Some individuals are pale and weak, and are commonly known as anaemic. Physiology tells us that the normal pinkish hue is

due to blood, and that blood is red because it contains in its red cells a substance called haemoglobin. This indirectly tells us that the pale individual has less haemoglobin, a fact which may be verified by measuring the haemoglobin in her blood. Physiology also tells us that the normal function of haemoglobin is to carry oxygen, and that the harder we work, the more oxygen we need. That explains why the anaemic person is weak. Further, physiology tells us how a normal person's red cells are formed, and how haemoglobin is manufactured. That gives us a rational way of looking for the causes of anaemia. For example, one of the substances needed for the synthesis of haemoglobin is iron. Correspondingly, a person deficient in iron has anaemia. If iron deficiency is the cause of anaemia in an individual, giving her iron would correct the anaemia.

To quote another familiar example, diabetes was considered incurable till about sixty years ago. Two young scientists, Frederick Banting and Charles Best, discovered through physiological studies on dogs that the substance which prevents normal individuals from passing excessive sugar in urine is insulin, which is manufactured by the pancreas. From this, it was concluded that an injection of insulin would cure a diabetic, and it turned out to be so. Besides diabetes, there are many other less common diseases which can be cured by supplying from outside some substance normally made by the body itself. Here we are employing no 'medicines' in the usual sense of the word. We are merely filling a gap in the body which is otherwise normal. This is possible only if we know enough about what is normal.

The examples given above are specific, and such examples can be multiplied many hundred fold. But one general fact brings out the relationship between normal and abnormal states of health better than any number of such examples. The normal body has in-built mechanisms for maintaining all vital functions close to a level which we consider normal. When a disease process results in an abnormality, it is the very same in-built mechanisms which correct the abnormality. For example, in case of fever, the return of the temperature to normal involves the same mechanisms which regulate the body temperature in the healthy state. As a result of these normal corrective mechanisms, majority of the common

ailments get cured even if left alone. With their knowledge of physiology, doctors can reassure their patient confidently that everything will eventually be back to normal, and in some cases, they can assist the normal regulatory mechanisms so that recovery from disease is accelerated.

It is said that a teacher who tries to teach without creating interest in his students is hammering on cold iron. It is hoped that the above account would motivate the reader enough to struggle his way through the book. Besides improving his knowledge about how his own body works, it is also expected that the book would excite his curiosity. The approach throughout the book is to encourage the reader to question, argue and reason. In the process, we also hope to make a humble contribution to creating a 'scientific temper', a dream cherished by Jawahar Lal Nehru. We are glad that our contribution is finally going to materialise during the Nehru Centenary year. It is difficult to anticipate all the questions that may occur to the reader, and space does not permit answering all those which we can anticipate. But the reader is welcome to write his queries to us. We may not know the answers to all the questions, but all letters will be replied, and many of the questions are sure to help improve the next edition.

Finally, it gives us great pleasure in thanking Professor H. D. Tandon, Director of All-India Institute of Medical Sciences till 1984, for writing a foreword to the book. We are also grateful to Dr. P.G. Mutalik, a young and brilliant colleague of ours, for his contributions to the chapter 'Higher Functions of the Brain'. Dr. C. S. Pandav, once a dear student, and now a promising young physician at the Institute, provided many of the clinical photographs in the chapter on hormones. Dr. S. C. Dash helped procure the picture of the dialysis unit and Dr. N.Bishnoi that of the blood bank. Dr. P. D. Gupta provided electron micrographs of the cell, and Dr. I. C. Verma the micrograph of chromosomes. Our thanks to them all, and to many other colleagues and friends who have helped in the preparation of the book but whose names have been inadvertently left out. Last but not least we would like to thank the numerous publishers for their generosity in granting permission

to use copyright material. Their courtesy has been acknowledged individually at appropriate places in the text. If the book is found useful, all the effort that has gone into producing it will be worthwhile.

June 29, 1989

R. L. BIJLANI
S. K. MANCHANDA

CHAPTER 1

HEALTH AND DISEASE

> 'Health means body ease. He is a healthy man whose body is free from all disease ; he carries on his normal activities without fatigue. Such a man should be able with ease to walk ten to twelve miles a day, and perform ordinary physical labour without getting tired. He can digest ordinary simple food. His mind and his senses are in a state of harmony and poise. This definition does not include prize fighters and such like. A man with extraordinary physical strength is not necessarily healthy. He has merely developed his musculature, possibly at the expense of something else'.
>
> —Mahatma Gandhi

It is the irony of language that the simplest of words express the most profound ideas. Take, for example, words like Life, Death, Love or Truth. Volumes have been written on them by the best of brains with the result that their connotation has only become more complex. Health and Disease are also words in a similar category. The demarcation between a healthy and a sick individual is not as clearcut as it seems. The subsequent chapters in this book deal with human physiology, i.e. they discuss the mode of functioning of different parts of the body in a healthy person. But because of the dividing line between health and disease being very thin, there would be all too frequent digressions into disease processes.

The terms 'health' and 'disease' often convey something different when used in different contexts. Even medical doctors use these terms from at least three distinct viewpoints. One may hope to do some justice to the complexity of the topic by discussing these viewpoints separately.

The scientific viewpoint

A living organism is comparable to a society. Different members

of the society have discrete functions. Some of them perform highly specialized duties ; others perform tasks that are not so skilled. The work that each individual performs contributes to the survival of the society by ensuring that the essential requirements of all the members are met. Smooth functioning of the society requires that the activities of the members be coordinated with one another. This coordination is achieved in different societies largely by market forces and state control in varying proportions. The influence of supply and demand on price automatically tends to balance the requirements and availability of commodities. If genuine scarcity or antisocial elements do not let market forces achieve fairplay, state control tends to ensure it.

In complex organisms like man, the body is made up of millions of tiny units called cells. (Chapter 3). Cells perform functions of varying degrees of specialization. Clusters of cells performing similar functions are grouped together in the form of organs. The cells of the stomach and intestines serve to take nourishment into the body, cells of the lungs take oxygen into the body, cells of the heart and blood vessels help deliver this nourishment and oxygen to individual cells all over, and cells of the kidneys assist in getting rid of waste products from the body. The chief requirement of every cell is that its interior and immediate surroundings should be suitably warm, salty and acidic. The range of temperature, salt concentration, and acidity* that is compatible with life is extremely narrow. In a healthy body, these parameters are maintained within this narrow range by regulatory mechanisms. Some of these regulatory mechanisms operate by short loops, somewhat like market forces. For instance, during exercise, the activity in concerned muscles increases. This results in an increase in the demand for oxygen. Increased oxygen consumption is accompanied by increased carbon dioxide and heat production in the muscle. If the blood flow that carries oxygen to the muscle, were to stay constant, soon there would be a dangerous rise in temperature and acidity (due to carbon dioxide) and fall in oxygen concentration. But, what actually happens is that only a slight fall in oxygen or rise in carbon dioxide concentration triggers an

*Blood and body fluids are slightly alkaline (or less acidic) compared to water. The degree of acidity is regulated within very narrow limits.

opening up of blood vessels supplying the muscle. Thus the blood flow increases, and the essential features of the internal environment of the body (acidity, temperature, etc.) are maintained. Just the opposite type of activity achieves the same result when the exercise stops decreasing the demand on oxygen. Besides such short loop feedback mechanisms, comparable to market forces, there are also regulatory mechanisms originating in the brain and endocrine organs. These mechanisms may be compared to state control. For instance, in the above example of exercise, the brain and endocrines bring about some opening up of blood vessels in muscles even before the exercise actually begins. The very thought of exercise is enough to trigger the change in blood flow to the muscles.

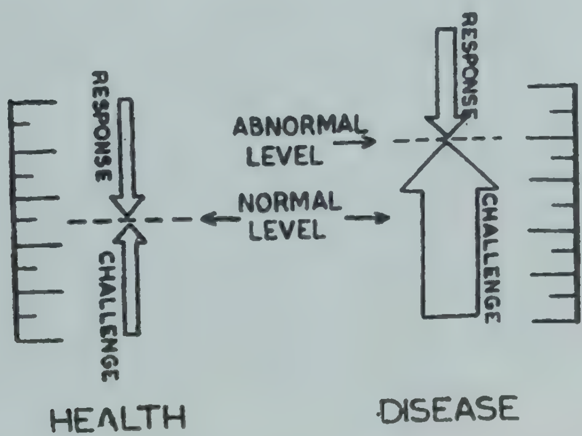

Fig. 1 Health and disease are a matter of balance between challenge and response.

The above example is just one of the large number of regulatory mechanisms which are mobilized to keep the body in good functioning order. That is to say that the cells of the body are provided a fairly constant internal environment, or homeostatic conditions. Derangement of homeostatic mechanisms is the fundamental basis of disease. Various forms of stress invoke the homeostatic mechanisms. So long as the intensity of the stress is within the compensatory powers of homeostatic mechanisms, the person is healthy. When the challenge stretches the compensatory mechanisms so much as to exceed their capacity, they break down, resulting in disease. An additional set of mechanisms (e.g. the immune mech-

anisms) might then come into play to restore health. To put it somewhat differently, health and disease are a question of balance between challenge and response (Fig. 1). If the challenge is overwhelming, even a 'very healthy' person may fall sick; on the other

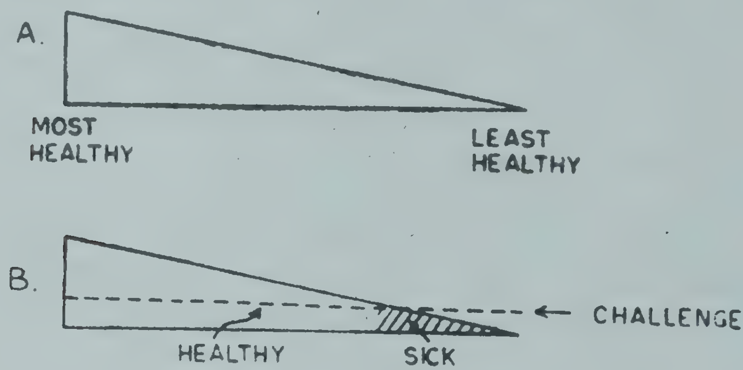

Fig. 2 There is no strict dividing line between health and disease. There is a continuous spectrum of health, which can proceed to disease under the impact of a strong enough challenge.

hand a challenge which can normally be handled quite adequately by most individuals, might overwhelm a 'less healthy' person, and make him sick. Thus there is no strict dividing line between health and disease. There is a continuous spectrum of health, which can proceed to disease under the impact of a threshold challenge (Fig. 2). An example will clarify this discussion further

Diabetes mellitus

The food that we eat has considerable quantities of carbohydrates. On digestion, carbohydrates yield glucose and related substances. When the body gets loaded with glucose, the pancreas (an endocrine gland) responds by secreting insulin, which helps the body in utilizing glucose. The pancreas continues to do this job untiringly, and with precision, all through, for years. As a person gets older, the capacity of the pancreas to respond by releasing insulin diminishes. The diminution is not to the same extent in all 'healthy' individuals, just as weakening of eyesight is not the same in all 'healthy' adults as they get old. If the glucose load during meals in an elderly individual regularly exceeds the residual functional capacity of his pancreas, he will develop manifestations

of a relative deficiency of insulin, which is called diabetes. Thus diabetes is basically a balance between the glucose challenge and the insulin response. Many diabetics can re-enter the 'healthy' category by altering the character of their diet so that the glucose load is reduced and is spread over a longer time. Further, many individuals who habitually consume a low glucose-challenge diet, continue to be in the 'healthy' category even though their pancreatic capacity declines to a level which would have forced some others into the 'diabetic' category.

This is the viewpoint that will be repeatedly illustrated by the subsequent chapters dealing with various organs and functions of human body. But doctors in the clinic have to adopt also another approach to health and disease, which may be called the clinical viewpoint.

The clinical viewpoint

Clinicians, or doctors, are also scientists. But their viewpoint is sometimes at variance with the strictly scientific viewpoint because the nature of their work requires combining science with some art, empiricism and compromise.

If all the known clinical examinations and laboratory tests were done on an individual, and found within normal limits, there is still a possibility that the individual might have a disease which cannot be detected by any of the tests so far available to medical science. In practice, however, the number of tests performed is limited due to constraints of time, money and convenience. Therefore, the chances of a disease escaping detection are indeed very real, and the disease so missed may be as serious as the cancer of the stomach. That is why, when asked to certify the health status of an individual, the doctor is usually contented with routine clinical and laboratory tests, the exact nature of which depends on the facilities available and the requirements of the situation. Even if the findings in all these tests are within normal limits, the scientist within the doctor tells him that the subject may not necessarily be healthy, and therefore, he gives him the technically safe certificate, N.A.D, which stands for 'no abnormality detected'.

Another dimension to the clinician's vision of health and disease is added by the large number of patients who visit him with

many types of complaints, but who, on clinical examination, are found fit, and all relevant laboratory tests are within normal limits. Scientifically, the patient is essentially healthy. But so long as the 'patient' has complaints, he is sick. Such patients, for whose complaints no physical basis can be discovered, are variously described as 'functional', hypochondriac, or loosely, as having a psychological problem. At the other extreme are 'patients' who personify Sydney Smith's words, "I have gout, asthma, and seven other maladies but am otherwise very well". They have very real complaints, for which there is an obvious physical basis, but they prefer ignoring their symptoms, and seldom visit a doctor. The clinician's doubts about health and disease may be summed up in the words of Hippocrates (400 BC), the father of modern medicine : "You can discover no weight, no form nor calculation to which to refer your judgement of health and sickness. In the medical arts there exists no certainty except in the physician's senses"

The public health point of view

One often comes across instances where figures of average life expectancy or infant mortality rate in a community are used as indicators of health. Such considerations are primarily the concern of a doctor engaged in public health activities. The public health man's perception of health and disease is coloured by the fact that he thinks in terms of groups. There is nevertheless, a public health definition of health of an individual, provided by the World Health Organization, i.e. health is a state of complete physical, mental and social well being, and not merely absence of disease or infirmity. Although very broad in scope, and ideal, one can understand how difficult it is to achieve, maintain, or identify such a state of health. Therefore, in practice, the public health man just keeps this definition in mind as a goal to be striven for. He measures the health of communities, not in terms of these ideals, but in terms of parameters like maternal or infant mortality rates. It has been found by experience that under the impact of public health measures such as immunization, sanitation, and maternal and child care, health statistics improve, the most sensitive among the figures being maternal and infant mortality rates.

Therefore, they are used by the public health man as parameters of health status of a population.

These are some of the criteria of health and disease familiar to doctors. That does not, however, preclude the importance of other viewpoints. The non-medical dimensions of health such as moral health or spiritual health are perhaps equally important. A society may be considered healthy and dynamic if it keeps throwing up large number of inventors, intellectuals, saints, authors or poets; it may be considered sick and below homeostatic levels if it is stagnant, although stable, or because it is vigorous but ridden with crime and violence.

CHAPTER 2

CELL : THE BASIC UNIT OF LIFE

You might recollect with pleasure one of your childhood days when you got hold of a piece of coloured glass and were trying to see through it almost every object you could lay your hands on. In much the same way, one might guess, Robert Hooke was playing with a microscope which he had invented himself. He was trying to see the magnified version of all sorts of things. One of

Fig. 3 This is how a slice of cork looks under the microscope. Robert Hooke was the first to call each tiny little compartment a 'Cell' (Reprinted with permission from Moon, T. J , Otto, J. H and Towle, A. Modern Biology, 1963 Fig. 4-1, p. 31. Courtesy : Holt Rinehart and Winston, Inc. New York, U. S. A.)

those things happened to be a thin slice of cork. He saw in it a sheet of innumerable minute compartments. He called each one of these tiny 'rooms' a cell (Fig. 3). Quite unwittingly, he had witnessed the structural and functional unit of all forms of life—plants as well as animals. That was way back in 1665. However, the concept of a cell being the unit of life took another two centuries to mature, and was first put forth by two German scientists—Mathias Schlieden, a plant scientist, and Theodor Schwann, an animal scientist.

The cell

If we peel a thin slice of the skin of a fruit or an animal and examine it under the microscope, it will be found to be composed of a large number of units, invisible to the naked eye. Each one of these units is called a cell. Similarly, each of the microscopic units which forms the liver, the brain, the muscles or the leaves, is also called a cell. All these cells have vastly different appearances. The differences are such as to make the cells suitable for the specialized function that they have to perform. For instance, the liver cells have a rich stock of 'reagents' for carrying out diverse

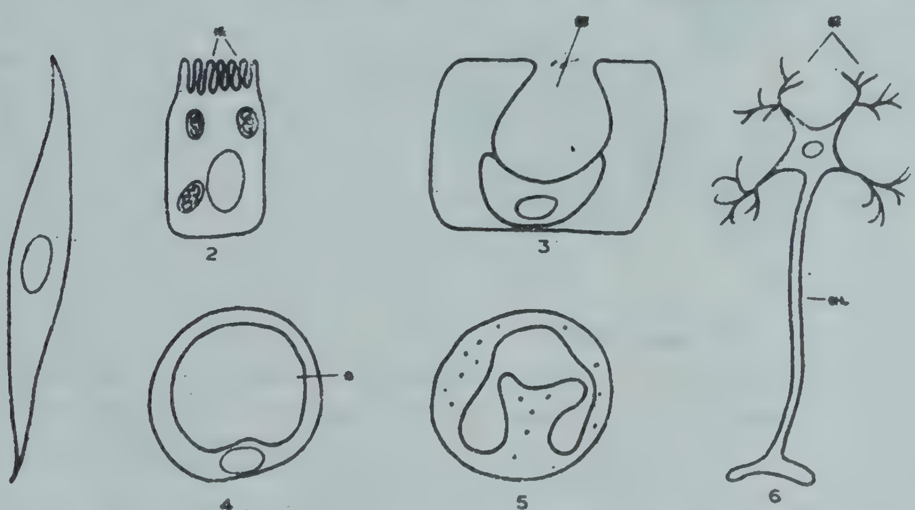

Fig. 4 All these diverse looking structures are cells of the human body. They are all called cells because they share many common features such as the presence of a nucleus surrounded by cytoplasm.
1, smooth muscle cell; 2, intestinal cell,* microvilli; 3, goblet cell,* mucus, 4, fat (adipose) cell, *fat vacuole; 5, neutrophill (a type of white blood cell); 6, neuron (a nerve cell), *dendrites (processes for receiving messages), **axons (processes for sending messages).

chemical reactions, the brain cells have elongated processes for transmission of messages, while the muscle cells carry long protein filaments arranged in such a way that they can slide into and out of one another resulting in a change in the length of the cell (Fig. 4). In spite of these differences, there are some basic features which are shared by most cells. These common characteristics have led the scientists to call all these diverse structures 'cells'.

In general, cells have a boundary that limits them from other cells, and also from their watery surroundings. The boundary, called cell membrane, is a dynamic structure with shifting doors and windows which allow substances to pass into or out of the cell in a selective manner (Fig. 5).

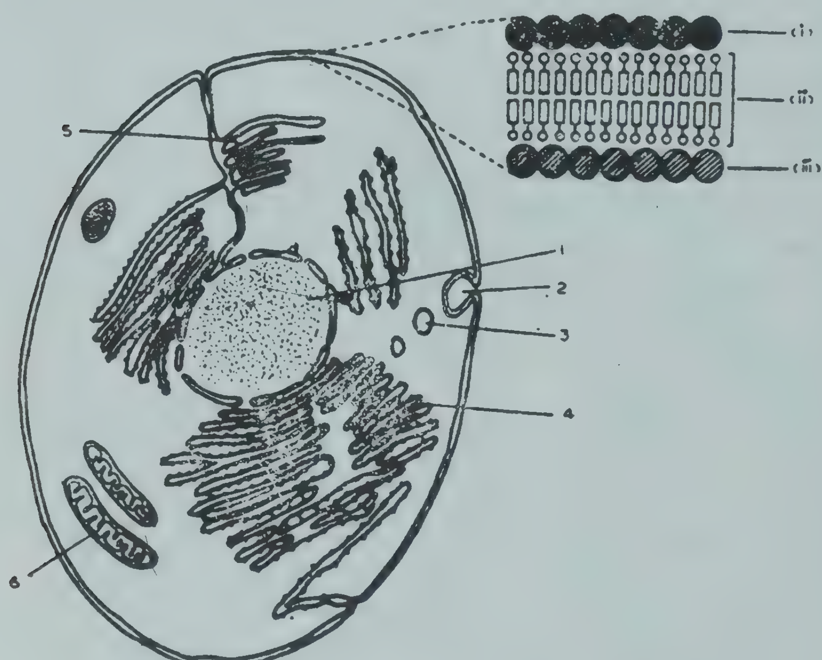

Fig. 5 Diagrammatic representation of a 'typical' cell as seen under an electron microscope. 1, nucleus; 2, a vacuole about to be formed; 3, vacuole; 4, endoplasmic reticulum (rough); 5, Golgi apparatus; 6, mitochondria.
At the upper right corner, a model of the cell membrane has been depicted schematically.
(i) outer protein layer; (ii), lipid layer; (iii), inner protein layer.

Within the cell, the most eye-catching structure is the spherical nucleus. The nucleus contains long, thin, coiled, thread-like entities

called chromosomes. Chromosomes carry the code for synthesis of proteins. One might say that what a cell does, and how it looks depends upon the type of proteins it manufactures. Thus chromosomes carry the message for the activities and appearance of the cell. Further details of this aspect will be discussed later in the chapter.

Besides the nucleus, the cell contains a fluid matrix called the cytoplasm. The structures present within the cytoplasm vary a lot, but among the important structures are the *mitochondria*, the 'power house' where the energy of various nutrients is tapped; the *ribosomes*, where the proteins coded in the nucleus are synthesized; *lysosomes*, which can break down in the cell any substance requiring harsh treatment, and various types of *vesicles* and *vacuoles* containing products which have just entered the cell, are about to leave the cell, or are being processed in the cell.

Most of these structures within the cell had been observed long ago with the aid of the light microscope. But the details of their structure were worked out only after the invention of the electron microscope. Compared with a light microscope, an electron microscope employs a beam of electrons instead of a beam of light. The wave length of a beam of electrons being much shorter than that of visible light, it is possible to obtain a very high magnification without losing clarity.

The cell membrane, about 75A° (1A° (Angstrom) $=10^{-10}$ metre $=0{\cdot}000\ 000\ 000\ 1$ metre) thick, when highly magnified, looks like a sandwich. It is three-layered with two similar layers enclosing a third different type of layer. The main constituents of the membrane are lipids and proteins. It has been proposed that they are arranged in the form of a bimolecular leaflet of lipids surrounded on either side by proteins. The membranes enclosing the nucleus and mitochondria are also simple variations of this basic pattern. The pores in the cell membrane through which transport of various substances takes place are so small that they cannot be seen even by an electron microscope. Their existence has been postulated purely on the basis of functional studies.

The envelope that surrounds the nucleus, or the nuclear membrane, has large pores visible under the electron microscope (Plate 1). The pores provide a path for the passage of large nucleoprotein molecules from the nucleus to the cytoplasm. These molecules

carry messages about the type of proteins to be synthesized in the cytoplasm.

The mitochondria are enclosed in a double membrane. The inner membrane is thrown into folds called cristae, thereby increasing its surface area. On the cristae are lodged the various enzymes required for harnessing energy from energy-rich compounds. The breaking up of these compounds is in many steps, and the enzymes are arranged in the same sequence as they are required. Mitochondria do not remain fixed at a particular position in the cell. Their movement is particularly striking in nerve cells where they may move several feet while travelling from the region of formation to where they are required to function.

The ribosomes are particles, about 100A° in diameter. They are attached to a system of membranous tubules called endoplasmic reticulum. In cells engaged in extensive protein secretion, the proteins formed on the ribosomes are concentrated in a system of vesicles or flat membranous cisterns called the Golgi apparatus (Plate 2). From time to time a vesicle is pinched off from the Golgi apparatus, moves towards the surface of the cell, and discharges its contents to the exterior.

On the one hand, materials are discharged to the exterior; on the other hand, particles, and even organisms like bacteria may be engulfed by some cells from the exterior (*phagocytosis*). They get walled off in a vacuole which fuses with lysosomes. The enzymes present in lysosomes break down the contents of the vacuole into simpler products. Among them, the useful substances are retained by the cell, and the waste products are discharged to the exterior.

Every cell is like a factory where a central authority (nucleus) issues instructions for some products (proteins) to be made by the highly skilled workers (ribosomes) with the help of energy generated in the power house (mitochondria) with many other skilled and unskilled workers doing various peripheral duties. It is this type of organised activity that we call life, and the cell is the smallest unit of an individual that displays it.

The hallmark of life displayed by each cell, however, is the ability to reproduce. Most of the cells in the body divide into two cells at a time. Each daughter cell is a copy of the mother cell, and contains a nucleus having exactly the same number and type of chromosomes as the mother cell.

Cell division is necessary during growth, and also later on in life for replacement of dead cells. The ability of the cells to divide varies in different parts of the body. Parts of the body which are subject to considerable trauma, e.g. the skin or the intestine, continually lose cells. Correspondingly, these are the parts which have the most brisk cell division. Highly specialised cells like those of the brain do not divide at all. It is indeed marvellous that cell division continues for decades, and yet produces exactly the same type of cells as the mother cell, and in just the right number. Occasionally something may go wrong with this fine regulation, and cells may proliferate far too rapidly. When that happens, generally the cells produced are also functionally useless. Such a situation is called cancer. Thus a patient having cancer has in his body, to start with, a focus where useless cells are being produced like mad. These cells perform no useful function but that does not prevent them from obstructing normal function. Also, these abnormal cells consume energy commensurate with their rate of division, thus making their victim malnourished. As time passes, the original site of cancer may no longer suffice for the growing needs of the tumour, and pieces of it get pinched off and travel via the blood stream to more hospitable sites such as the liver and lungs. The tumour cells continue their mischief wherever they travel till various parts of the patient's body function very poorly indeed, and he just cannot meet the heavy nutritional demands of the unwanted cells. This, briefly, is the typical story of the unfortunate person afflicted with cancer somewhere in the body. Unfortunately we do not fully understand what makes the cells behave in this fashion. The causes certainly are multiple, and are different for different cancers. In some cases, the predominant cause is a virus, in some cases a chemical, and in some cases a chronic irritant like cigarette smoke. In spite of all the advances that have been made recently, cancer continues to be an essentially incurable disease. The treatment is aimed at relief of symptoms and prolongation of life. The chief lines of treatment are drugs, radiation and surgery. Drugs and radiation affect cancer cells adversely, but they do not entirely spare cells in the body that normally divide rapidly, e.g. the intestinal cells. Hence the serious side effects of drugs and radiation employed for cancer treatment. Surgery is useful only in early stages when the growth

is still small, and cancer cells have not spread all over the body. In view of this bleak outlook, the best one can do is to adopt all possible preventive measures, some of which have been mentioned at appropriate places in the chapters that follow.

That every cell does have a streak of life is shown by the fact that it is possible to isolate some cells from a man or animal, and when these cells are suspended in a medium which supplies them all their essential requirements, they continue to live, grow and multiply. This technique is known as *cell culture*. Cells kept like this have been maintained alive and dividing for decades.

Organisation of cells

The millions of cells of a man are grouped into somewhat poorly demarcated systems such as the circulatory system, respira-

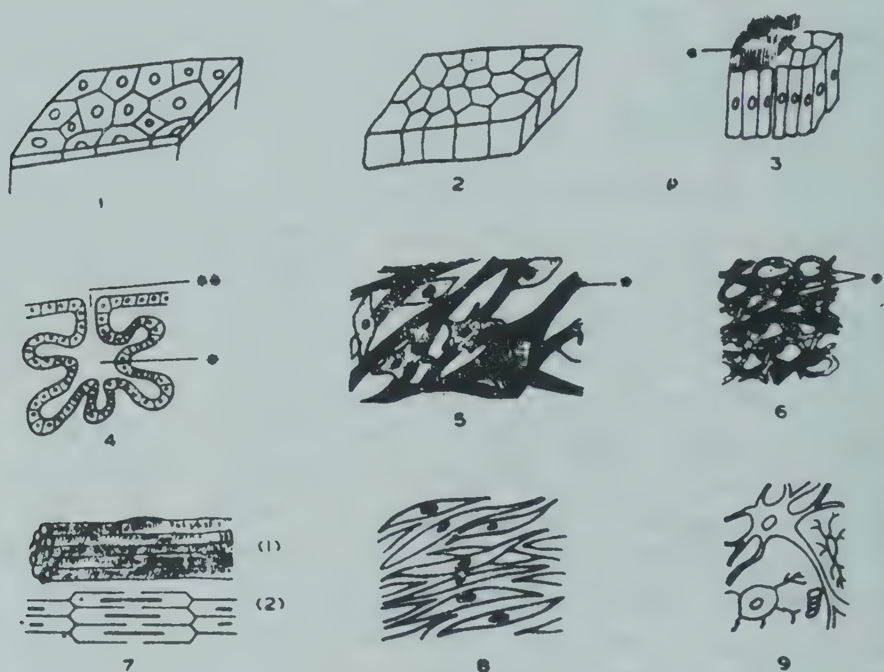

Fig. 6 An assortment of tissues.
1-4. epithelial tissues (lining tissues); *, cilia
4, a gland lined by epithelium; *, cavity of the gland containing the secretion; **, opining for discharging the secretion
5, connective tissue (for connecting structures and filling spaces); *, fibres
6, adipose (fat) tissue; *, fat
7-8, muscle tissue
9, nervous tissue

tory system, digestive system, and nervous system. Each system is composed of a number of organs, for instance the digestive system comprises mouth, salivary glands, food-pipe, stomach, intestines etc. Each organ is further composed of a number of tissues (Fig. 6). A tissue is a collection of similar cells playing a discrete role in the function of an organ. For instance within the lungs there would be tissues concerned with exchange of gases, and tissues imparting elasticity to the lungs.

One cell—One animal

There are also some animals which are entirely made up of a single cell. One such animal is called amoeba. These animals are thought to be among the earliest that appeared on earth. These animals can ingest nutrition at any point on the surface, digest and utilise their food within their tiny body, discharge the waste products from their surface into the mighty sea that surrounds them, and reproduce by dividing into two similar cells. Because of the huge volume of the water surrounding them, and their own tiny size, they can maintain a steady and healthy composition in their interior without spoiling their environment.

Man and other large animals are not as different from an amoeba as they appear (Fig. 7). It is only that because of our large size and terrestrial existence, our problems are more complex, and they have been solved by complex mechanisms. We are not surrounded by sea but we have carried a bit of the 'sea' within us. Because of our large size, we have had to develop a tubular tree (circulatory system) to *transport* and *distribute* the sea to every cell of our body. The circulatory system is aided by a pump (heart) which keeps the 'sea' in motion. Because the small volume of the 'sea' within us does not provide much dilution of our waste products, we have developed special mechanisms to cleanse the environment of our cells. Finally, because of our complex organization, we need *coordinating* mechanisms to match the activities of the various cells of our body. For instance, when we sit down to a meal, the stomach should know that it will soon get busy so that it can get ready with its digestive juices; and during exercise, the muscles put to use should receive more nutrition through controlled overactivity of the breathing and circulatory systems.

All these transport, distribution, cleansing and coordinating mechanisms will be dealt with in the subsequent chapters.

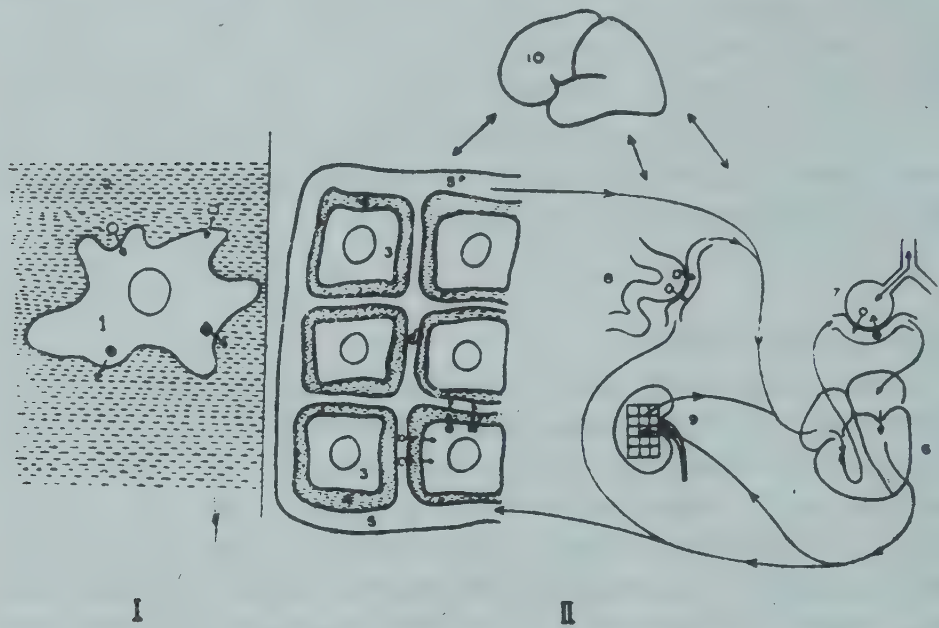

Fig. 7 Amoeba (I) and man (II).
The amoeba (1) is surrounded by sea water (2) The organism exchanges nutrients and waste products directly with the sea water. The cells of man (3) are not very different, being surrounded by the intercellular fluid (4) very similar to sea water in its composition. The fluid passes on the nutrients from the blood to the cells, and the waste products in the reverse direction. Blood is taken to the cells by the arterial system (5) which branches off into capillaries (5′) so as to take the blood close to every cell. The blood, having given the nutrients to the cells, and having collected the waste products, joins the venous system (5″). The blood is kept in motion by the heart (6). Nutrients are replenished and waste products finally discharged by exchanges taking place chiefly in the lungs (7), intestines (8) and kidneys (9). The cells of the heart, lungs, intestines and kidneys are also supplied by blood in the same way as shown for other cells (3). Because the entire system is complex, its different components need to be co-ordinated. This function is performed by the nervous and endocrine system, shown symbolically in this diagram by the brain (10). O, Oxygen; □, other nutrients; ●, carbon dioxide ■, other waste products.

Similar but not the same

We are all made up of similar cells, but are obviously not the same in every respect. The colour of our eyes, hair or skin is different. Some of us have curly hair and others straight; some

of us have a long nose and others short. The secret behind this variation is located in the nuclei of our cells. The nucleus of each cell of a human being has 46 chromosomes (Fig. 8). Not only is their number constant, the shape of chromosomes is also rather constant. The 46 chromosomes in each cell can be sorted out into 23 pairs, the two members of each pair being apparently similar. Similarity in the number and shape of chromosomes is responsible for the similarity of all human beings. However, underneath this

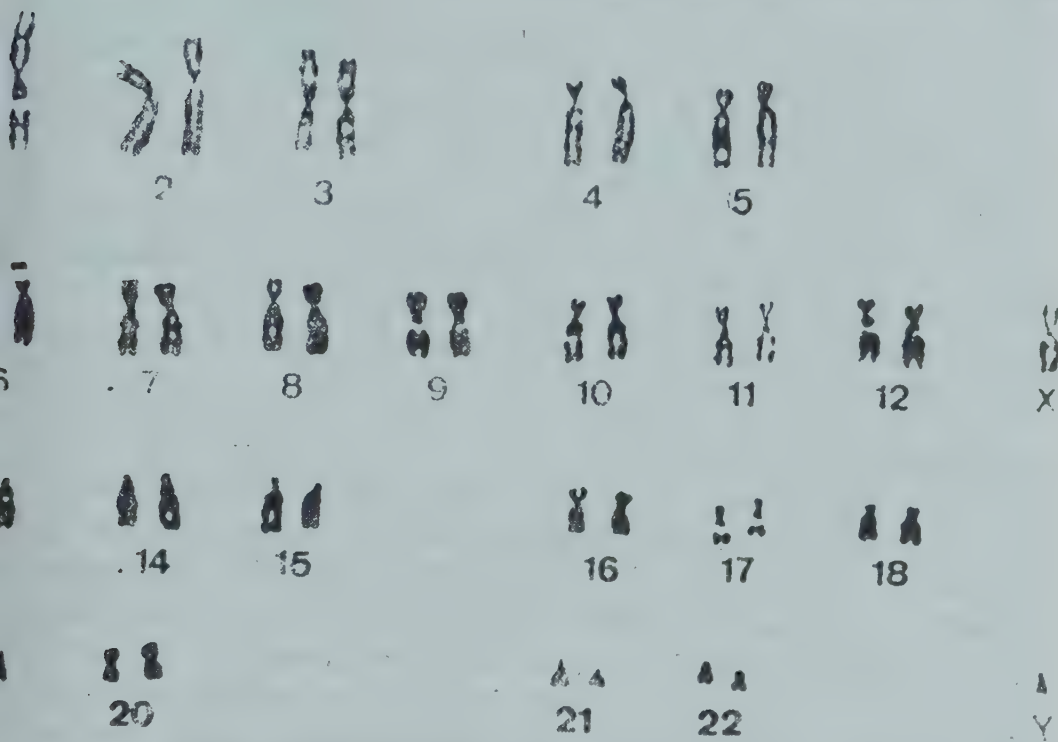

Fig. 8 The chromosomes of a normal human male. Note the twenty two pairs of autosomes and the pair of sex chromosomes (X and Y). In a female, both sex chromosomes are of the X variety. (Courtesy: Dr I C Verma Head, Genetics Unit, AIIMS, New Delhi)

similarity of chromosomes are minute molecular differences. These minute differences are responsible for the differences between individuals. Each chromosome codes for hundreds of characteristics. The portion of a chromosome that codes for one character is called a gene. Corresponding portions of two chromosomes constituting a pair have genes for the same character, e.g. colour of eyes. But one of them may code for dark eyes, another for grey eyes. The individual will, however, have the character coded by

one of them (called the dominant character). For instance, if in the above example 'dark eyes' is the dominant character, the individual will have dark eyes although he is carrying genes for dark as well as grey eyes.

The key substance making up the chromosomes is deoxyribonucleic acid (DNA), When a cell divides, the DNA also doubles in quantity, so that each daughter cell receives its full quota. Not only is the sharing quantitatively exact, it is also qualitatively an exact replica of the mother cell down to every single molecule. That is how the characters of an individual are maintained. Further, the molecular details of DNA in different individuals are not entirely identical. The greater the differences, the greater the dissimilarities between individuals.

DNA codes for characters through the agency of proteins. The nature of DNA determines the nature of proteins that a cell makes. What a cell does, and how it looks, depends on the proteins it makes. A protein, or a group of proteins, determines a character like the colour of the eyes.

Inheritance of characters

It was mentioned above that when cells divide, they form daughter cells having exactly the same number of chromosomes as the parent cells. This is true of all cells in the body except some selected cells in our sex organs. When these cells divide, they form cells having only one representative from each pair of chromosomes. Thus in human beings, these cells would have only 23 chromosomes — one from each pair. These cells are called *gametes*. The gametes formed by men are called sperms; those formed by women are called ova (singular, ovum). A new life begins when a sperm unites with an ovum in the mother's womb. During union, called fertilization, the nuclei of the sperm and the ovum fuse into one and the resulting nucleus has 23+23, i.e. 46 chromosomes. All the cells of the child are now formed by repeated division of this united cell, called *zygote*. Since its starting cell has 23 pairs of chromosomes, all the cells of his body also come to have the quota of chromosomes which is characteristic of all human beings.

Thus each of us has received half our chromosomes from the mother and half from the father. Since our parents also inherited their chromosomes in a similar way, and so on, our chromosomes

have our whole ancestry inscribed on them. That is why we bear a resemblance not only to our parents but also to many other relatives.

Nature vs nurture

A person's characteristics do not depend entirely upon his heredity. Heredity and environmental factors together shape an individual.

The influence of heredity on physical features is marked and ordinarily irreversible. Besides, heredity does influence behaviour and mental make-up also. How else can one explain the immense diversity in personalities and intellectual calibres of orphans brought up together in the same surroundings ? However, brothers and sisters, in spite of their very similar heredity, grow up to be very different types of individuals if brought up in different conditions, thereby illustrating the influence of environment. Thus heredity and environment both contribute to the development of an individual. The relative contribution of the two factors is the topic of a perennial debate. On one side are the idealists who believe that we are all born the same, and on the other are the racialists who feel that some races are intrinsically better because of their superior genetic make-up While the racialist is wrong because very dull, average and very bright individuals have a similar distribution in every race, the idealist should also understand that we are all born with different potentialities. We are all born equal, but not the same. None is born superior or inferior, but all are born different. This understanding should help us in adopting a more rational and sympathetic attitude towards the less talented ones who, due to no fault of theirs, do not have a good enough genetic make-up or have not been able to live in a sufficiently stimulating environment.

CHAPTER 3

BLOOD : THE VITAL FLUID

Only a living animal bleeds on injury ; a dead animal does n bleed. It is probably owing to this observation that blood has bee associated with life since times immemorial. The association pe sists even today, and is quite true. Devotion to God, country humanity has often been expressed by willingness to sacrifi blood for their sake. Blood has, though incorrectly, also be considered the carrier of hereditary characteristics; hence the expr ssions like 'blue blood', 'royal blood', and so on. But today we a quite clear about the role of chromosomes in genetic transmissic and know that blood has no direct relationship with heredi (Chapter 2). The sentiments attached to blood may not be justifie but blood is certainly the vital fluid of life. It is constantly on t move, visiting every cell of the body, distributing nutrients ar collecting waste. Besides, it also has an important role in defen ing the body from infective agents and other insults.

Composition of blood

Blood looks like a homogenous red fluid to the unaided ey But when it is spread into a thin layer and observed under a mi roscope, it is found to be a suspension of different types of cells a liquid called the *plasma* (Fig. 9). Most of the cells are fai yellow, and without a nucleus. A dense accumulation of these ce is responsible for the red colour of the blood. That is why the cells are called erythrocytes or *red blood cells*. Besides red bloo cells, there is a much smaller number of two other types of ce —the leucocytes, or *white blood cells* (in fact colourless) and t thrombocytes, or platelets (because they resemble small plates).

Plasma

Plasma is a straw coloured liquid, about 90% of which is wat

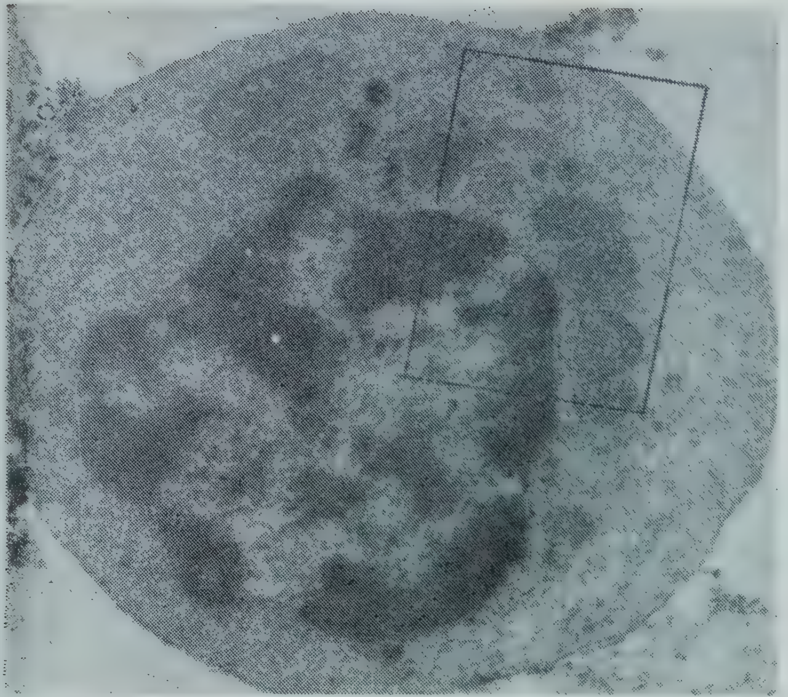

Plate 1. An electron micrograph of a cell.
1. cell membrane 2. cytoplasm 3. nucleus 4. mitochondria 5. endoplasmic reticulum (rough) (X 15,250).

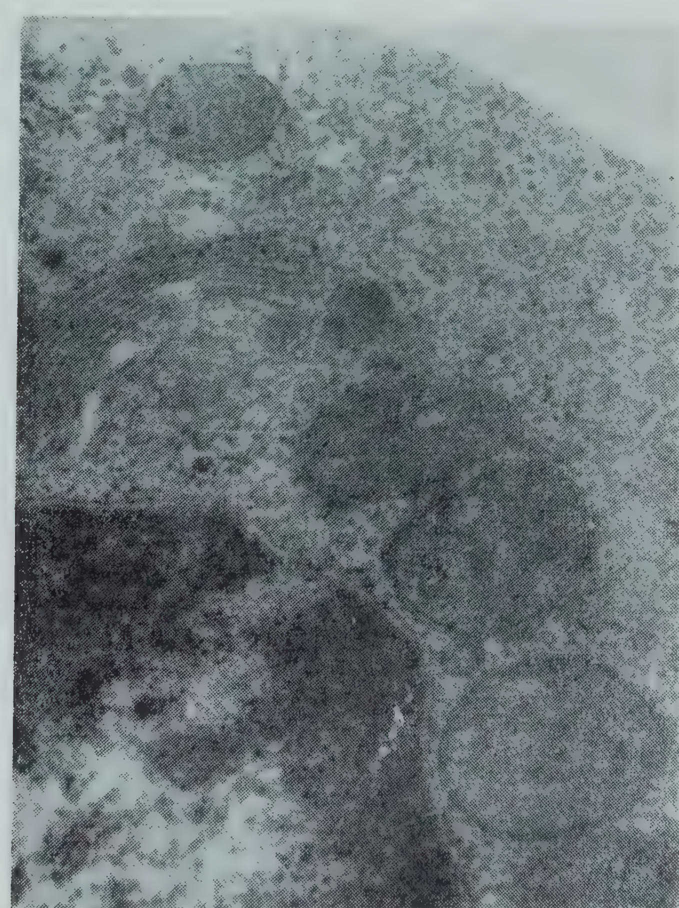

Plate 2. An enlarged view of the rectangle marked in Fig. 3.4 A.
1. nuclear membrane 2. endoplasmic reticulum (rough) 3. mitochondria (X 48,000). (Courtesy: Dr P D Gupta, AIIMS).

Plate 3. A healthy volunteer donating blood for an unknown fellow-being. (Courtesy: Dr Neeraj Vishnoi, Blood Bank, All India Institute of Medical Sciences, New Delhi).

The rest are solids, of which a *small* fraction consists of salts. The chief salt dissolved in plasma is sodium chloride, or common table

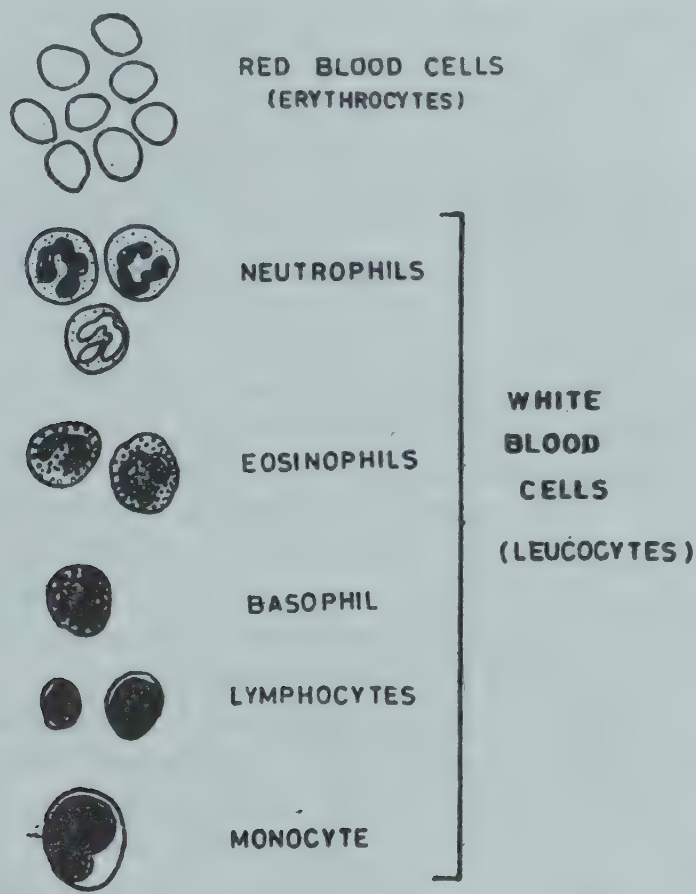

Fig. 9 Different types of cells found in human blood.
(a) Erythrocytes, or red blood cells
(b) Leucocytes, or white blood cells
(c) Thrombocytes, or platelets

salt. The salinity of plasma is approximately one-third that of sea water, reminding us of our aquatic origin (Chapter 2. Fig. 7). The discrepancy in salt concentration is possibly because when life originated, the sea was not as salty as it is today. Much the *larger* fraction of solids in the plasma consists of a large variety of proteins. The proteins in the plasma impart to it sticky quality (viscosity). One of the proteins (fibrinogen) is essential for clotting of blood (see below). Some other proteins (globulins) aid in the defence mechanisms of the body. Some plasma proteins belong to the family of chemical messengers. Besides, many of the plasma proteins carry small molecules of the chemical messengers, and

minerals like iron, copper or calcium. The binding of these substances to proteins helps in their safe delivery to their destination, and prevents them from getting lost while circulating in the blood stream. The small molecules may be compared to small children, who run the risk of getting lost on their way to or from school unless accompanied by an escort (here, plasma proteins).

In addition to all the above substances, digested foods like glucose, fatty acids and amino acids, and waste products like carbon dioxide and urea are also transported in the plasma.

Red blood cells

Red blood cells are the most numerous of the blood cells. Each cubic millimetre of blood, which is about the volume of a pinhead, contains 5 million red blood cells. Two drops of blood contain as many red cells as the population of India. The red cells have undergone so much metamorphosis in the process of adaptation for a specific function that they are hardly recognizable as cells. They neither have a nucleus nor mitochondria. They are essentially small microscopic bags of haemoglobin, a reddish coloured protein containing iron. Haemoglobin has a remarkable affinity for oxygen. But it gives up its oxygen in conditions of oxygen lack. It is thus that haemoglobin makes it possible to deliver oxygen to tissues which need it. On the other hand in the presence of excess oxygen, haemoglobin soaks up oxygen like a sponge. This takes place in the lungs. The cells of the body always have less oxygen than the blood which comes after passing through the lungs. Therefore, haemoglobin carries the oxygen it picks up in the lungs, and places it at the disposal of the cells.

Haemoglobin has about 200 times as much affinity for carbon monoxide gas as for oxygen. The result is that even in small concentrations, carbon monoxide acts as a very strong competitor of oxygen for getting attached to haemoglobin. Further, once attached, haemoglobin does not easily surrender the carbon monoxide. Therefore, levels of carbon monoxide above a certain minimum can block enough haemoglobin so as to leave very little for combining with oxygen. In such a situation, the oxygen carried by the blood would fall to very low levels. That would result in deficiency of oxygen delivered to the cells. With a dangerously low supply of oxygen, cells of the body cannot live. Therefore

carbon monoxide acts as a poison, and can cause death. Carbon monoxide is a component of smoke. Therefore, it is important that one does not sleep in a poorly ventilated room which has been kept warm by a smouldering fire. Cigarette smoke, and the smoke emanating from automobile exhausts, also have carbon monoxide. While smoking, from 2 to 10% of a smoker's haemoglobin combines with carbon monoxide, and is thereby rendered physiologically useless. The effect would be compounded in an area with high traffic density.

The normal quantity of haemoglobin present in blood is 12-15 gm in every 100 ml* of blood. A decrease in this quantity is called *anaemia*. Since haemoglobin is responsible for the red colour of the blood, and to some extent also that of the skin and mucous membranes**, anaemia results in reduced redness (pallor) of the skin and mucous membranes. The best region to assess the quantity of haemoglobin is the mucous membrane of the roof of the mouth (palate).

In order to understand why a person might have anaemia, it is essential to understand that the red blood cells in the body are not static. Old red blood cells keep getting destroyed as they get old, and fresh young cells keep replacing them. The average life span of a red cell is about four months. Even so, because of their large number, the body has to manufacture trillions of red cells every day The factory where they are produced is located in the hollow of the bones (bone marrow). They are formed by the transformation of undifferentiated cells which have a nucleus but no haemoglobin. Gradually the precursor cell loses its capacity to divide, sheds its nucleus, and acquires haemoglobin. The young red blood cell is then released into the blood stream. It is jostled around from place to place for about four months. During this period it grows old. When it loses its vitality, it is trapped by the spleen or the liver and broken up into its components. Most of the essential

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*'ml' stands for millilitre. It is a unit of volume, and designates the space occupied by a cube, each side of which is 1 centimetre. 1 ml is thus the same as 1 cubic centimetre (c.c.).

**Mucous membrane is the name given to the lining of the internal organs of the body, e.g. the mouth, stomach or urinary bladder. It is much more delicate than the skin which lines the outside of the body.

components remain within the body and are used again to form fresh red cells.

Logically then, anaemia can result from decreased production or increased destruction of red cells, or from abnormal blood losses. In our country, the commonest causes of anaemia are :

(i) decreased production due to deficiency of iron, folic acid or proteins, which are required for the manufacture of red cells. The deficiency is particularly seen when the requirements of nutrients are increased, as during child bearing, nursing and childhood.

(ii) abnormal loss of blood. A common abnormal loss of blood is in women due to excessively heavy menses.

Presence of hookworms in the intestines too can cause a loss of blood. Hookworms are about a centimetre long, thread like worms, which cling to the walls of the intestines by means of their tiny teeth. Their teeth, though tiny, are sharp enough to cause a little bleeding. For one variety of hookworms, it has been estimated that each worm sucks blood at the rate of 0·03 ml/day or about 1 ml/month. That may appear to be a minor loss. But keeping in mind that the number of worms harboured by a patient runs in hundreds, and may go upto a thousand, the loss over a period of few months is substantial. In a hypothetical case, a patient harbouring 500 worms would lose about half a litre of blood in one month. It is difficult for the red cell producing mechanisms to compensate for such a heavy loss, and hence the anaemia.

Accordingly, the treatment of anaemia depends upon its cause. If it is due to a dietary deficiency, it should be made up. If it is due to abnormal loss of blood, the underlying disease should be treated.

White blood cells

White blood cells are far less numerous than the red cells, the ratio being one white cell to every 600 red cells. They are, on the average, slightly larger than the red cells, and differ from them in three important respects. Firstly, they have nuclei. Secondly, they do not contain haemoglobin, and are therefore nearly colourless; that is why they cannot be seen under the microscope unless coloured by some special chemicals. Thirdly, some white cells can move and engulf particles or bacteria much like an amoeba. The

process is called phagocytosis (Fig. 30.) Phagocytosis is one of the defence mechanisms of the body.

White blood cells are further subdivided into five groups according to the microscopic appearance they assume when stained by some popular dyes :

(i) neutrophils, with a lobed nucleus and purple granules, in the cytoplasm. They are highly phagocytic in nature.

(ii) eosinophils, with a lobed nucleus and red granules in the cytoplasm. They are associated with allergies. Probably they reduce the ferocity of allergic reactions.

(iii) basophils, with a lobed nucleus and blue granules in the cytoplasm. They are probably important for healing.

(iv) Lymphocytes, with a large round nucleus, almost occupying the whole cell. They are intimately associated with the immunological defence mechanisms of the body.

(v) monocytes, with a kidney shaped nucleus and no granules in the cytoplasm. They are a part of the phagocytic system of the body.

Platelets

Platelets are much smaller than red or white blood cells and are devoid of nuclei. Their number is intermediate between that of red and white blood cells, there being one platelet to around twenty red cells. Platelets are, in fact, mere fragments of a cell. However, days are gone when they were considered artefacts. Today they are known to be mini-laboratories containing more than eighty biologically active substances. Probably we do not still know all the functions of platelets. The best understood, and perhaps the most important, role they play in the body is in checking the bleeding from an injury (haemostasis, haima, blood : stasis, a standing).

Haemostasis : Whenever there is an injury to the body, except in unusually severe injuries, the bleeding normally stops within a few minutes. This is brought about, first, by an immediate narrowing of the small blood vessels at the site of injury. Platelets contribute to this step by liberating a chemical called serotonin. In minor injuries, narrowing of blood vessels may be enough to stop bleeding within a few seconds. If it is not enough, the platelets start collecting at the site of injury and form a plug

which blocks the bleeding slit. But this plug is not firm enough to stop all oozing. Hence follows the next step wherein the blood which is oozing out itself forms a solid mass (clot).

Clotting (*or coagulation*) of blood is a complex process during which one of the plasma proteins (fibrinogen) forms a lacy mesh in which the various blood cells get entangled. Within a few minutes, the clot becomes more firm by the fibrous strands of the network getting pulled like a ligature (retraction of the clot). Platelets participate in the clotting process and are the sole agency responsible for retraction of the clot. Thus platelets participate in all aspects of haemostasis.

Blood transfusion

In the 19th century, a German Physician suggested that temperamentally incompatible couples could achieve a happier and more harmonious relationship by cross-transfusing their blood. Today no scientist would give this advice to save a marriage, but there are many situations where blood transfusion may save life. Most of these situations are ones in which the patient has lost a large volume of blood, as in injuries and surgical operations. Blood is best replaced by blood. No equally effective artificial substitute has yet been manufactured.*

It is common knowledge that anybody's blood cannot be transfused into anybody else. The bloods have to be compatible to avoid any harm to the recepient. The basis of compatibility is the similarity in the type (or group) of blood. Strictly speaking, probably no two bloods are exactly alike. But for practical purposes, the blood of an individual can be assigned to one of the four groups : A, B, AB and O. The classification is based on the type of substances present on the surface of red blood cells. The groups signify whether a substance 'A' or 'B' is present, both are present or neither is present. For two bloods to be compatible, it is not sufficient that their ABO group be the same, because

*In case blood is not available, saline (salt water) is infused in an emergency to replace the volume lost temporarily. If a high molecular weight substance like Dextran is added to the saline, it stays longer in circulation. Some fluorocarbons have recently been discovered to offer promise as substitutes for oxygen-carrying function of the blood. However, a substitute for all functions of the blood is yet to be found.

there might be other differences between them. Therefore, in addition to matching of groups, before a blood transfusion is done, a drop from the blood of the donor and recepient each are actually brought in contact with each other in the laboratory and their behaviour observed under the microscope. If there is no damage to the red cells of the donor, the bloods are considered compatible.

Blood groups transcend all racial and geographic barriers. The group B blood of an Indian has as much chance of being compatible with a group B blood of an African or American as with a group B blood of another Indian. Blood groups do not respect family ties either : the blood of parents and children is not necessarily compatible.

It is not always possible to find a suitable donor whenever blood is required. Therefore, blood banks have been set up where a considerable quantity of blood of all groups is stored. Whenever a patient requiring blood transfusion comes, a suitable blood is selected from the bank and used for him. Thus a donor generally does not know who receives his blood, and therefore, does not suffer vain glory. The recepient is equally ignorant of the identity of the donor, and therefore, does not suffer obligation or embarrassment. That makes blood donation an ideal donation (Plate 3). The volume of blood removed at a time from the donor is only about 1/10th to 1/15th his total volume of blood. This bit of blood is hardly missed by a person in good health. The blood lost is replaced in a few weeks. Therefore, a blood donation can be safely made every three months. However, to increase the margin of safety, one might donate the blood only once or twice in a year. Unfortunately we have very few regular voluntary donors in India. Most of our donors are professional donors who donate blood because they need the money they get for it. Because of the circumstances which compel them to sell their blood, they donate blood more frequently than they should, are undernourished and anaemic, and often conceal having had malaria, jaundice, or veneral diseases, which may be transmitted to recepients through their blood.

Testing of blood

Blood, being the carrier of the body, mirrors the changes taking

place everywhere in the body. Therefore, it is often tested in many diverse diseases. The most commonly performed tests are:

(i) estimation of haemoglobin;

(ii) counting of white blood cells. White blood cells, being involved in defence mechanisms, are increased in almost all infections and major injuries;

(iii) counting the relative percentage of different classes of white blood cells. The type of white blood cells which increase in different varieties of infection are different;

(iv) the level of various substances in the blood. Blood levels can give valuable information about supply, production or disposal of a substance. For instance, decreased utilization of glucose in diabetes gives rise to high levels of glucose in the blood; and decreased synthesis of proteins in a person with a diseased liver reduces the plasma proteins; and

(v) detection of bacteria. In many infections, the infecting organism is present in the blood stream.

As can be seen from these few examples, blood tests may be of great diagnostic value in some cases. Besides, they also help in objective assessment of the treatment. If serial tests before and during treatment show a steady improvement, it supports the physician's approach to the patient and encourages them both.

Blood has rightly been considered the vital fluid. Loss of blood leads to death in much the same way as deprivation of air, water or food. It happens because blood brings these vital substances to the cells in every part of the body. By doing its many jobs of feeding, ventilating and protecting our cells, the blood keeps us alive.

CHAPTER 4

BLOOD ON THE MOVE : HEART AND BLOOD VESSELS

We are alive only so long as our cells are alive. Our cells stay alive so long as they are supplied with nutrients and cleared of their waste products. Blood does this job for every cell of the body. But it is remarkable that it does so while moving in, and remaining essentially confined to, an extensively branched tree of tubular structure called blood vessels. This is possible because there are portions of this tree which come very close to every cell of the body. These segments of the tree are called *capillaries*. Of all the blood vessels, the diameter of the capillaries is the smallest, and their walls the thinnest. The walls of capillaries are only one-cell thick, and have pores which allow several blood borne substances to pass through them.

Between the walls of the capillaries and the cells is a narrow space containing a fluid. It is this fluid which exchanges materials directly with the blood as well as the cells. This fluid is called lymph. Lymph is formed by a bit of the water and nutrients seeping through the walls of the capillaries.

Nutrients, including oxygen, are present in a higher concentration in the blood than in the cells, and therefore, pass out of the blood stream and move into the lymph. The lymph passes on these substances to the cells. Similarly, carbon dioxide and other waste products, being in a higher concentration in the cells than in the blood, move out of the cells into the lymph. The lymph passes them on to the blood.

Thus each cell of the body is surrounded by a liquid containing food and oxygen in much the same way as is an amoeba. The lymph provides a private mini-ocean to every cell with its attendant wetness, warmth and evenness.

How the blood reaches the capillaries

Blood moves into the capillaries from the *arteries*. Arteries are large blood vessels which bring the blood from the heart. They divide and subdivide repeatedly into smaller arteries. A small artery enters every organ and divides into a network of capillaries within the organ. The capillary network is arranged in such a way that every cell is reasonably close to a capillary.

Where the blood goes from the capillaries

The blood leaving the capillaries enters small veins. Small veins unite to form larger veins and so on, till finally two large veins are formed. One of them brings the blood from the upper parts of the body to the heart, the other brings it back from the lower parts of the body. The route of blood may thus be summarised as follows :

Heart → Arteries → Capillaries
Capillaries → Veins → Heart

The above circuit is called the systemic circuit.

It would be noticed that in the above circuit there is neither provision for replenishment of the oxygen which has been consumed by the cells, nor any explanation of how the carbon dioxide which has been dumped into the blood by the cells is finally removed from the body. This rejuvenation of blood is brought about by the lungs. For taking the blood to the lungs there is another circuit, the pulmonary circuit, which may be depicted as follows :

Heart → Pulmonary artery → Pulmonary Capillaries (in the lungs)
Pulmonary Capillaries (in the lungs) → Pulmonary veins → Heart

The pulmonary veins bring back the oxygenated blood from the lungs to the heart. It is this oxygenated blood that the heart pumps into the arteries of the body. An integrated picture of the two circuits is shown in Fig. 11.

At this juncture, one might mention the following facts, which are self-evident from the above discussion.

1. All arteries carry blood away from the heart. All veins bring blood back to the heart.
2. All arteries, except the pulmonary arteries, carry oxygenated blood. All veins, except the pulmonary veins, carry deoxygenated blood*.

Besides oxygen, there are other nutrients. Most of these are added to the blood while it passes through the digestive tract. Besides carbon dioxide, there are other waste products. They are removed from the blood in the kidneys. This does not mean that cells of the digestive tract themselves do not need nutrients, or that the cells of the kidneys do not produce waste products. It is only that while the blood is passing through these parts of the body, something happens to it which is in addition to what happens to it everywhere else. These facts have been depicted in Fig. 7, but the details of digestion and kidney functions are given in subsequent chapters.

HEART : THE WONDERFUL PUMP

The major function of blood is transport, and clearly, to be able to perform its function, it must move. The push for the motion of blood is provided by the heart—a wonderful pump indeed which goes on working untiringly more than seventy times every minute, often for more than seventy years. From the earliest of times, man has realized the importance of the heart. Our language testifies to this fact, particularly the language of the poets. We talk of a man being broken hearted, or light hearted, and a meal can be hearty, as can congratulations.

The heart is fist-sized, weighs about 250 g, and is placed in the left side of the chest between the two lungs. Functionally speaking, the heart may be considered to consist of two pumps—the right heart and the left heart. The two sides of the heart are separated by an unbroken partition. Each side of the heart is further subdivided into two chambers by a perforated partition which is guarded by a valve, however. On either side, one of the chambers is called the *atrium*, and the other *ventricle*. Thus there

*If these two sets of statements are not clearly understood, it is advisable to go back to the beginning of the chapter. The first statement gives the true distinction between arteries and veins. The second statement gives the basis a well as fallacy of the popular notion that arteries carry 'pure' blood while veins carry 'impure' blood.

are right atrium and right ventricle ; left atrium and left ventricle (Fig. 10). Roughly speaking, only the ventricles are the pumps—the atria serve as reservoirs which pass on the blood to the ventricles for pumping. The left ventricle pumps the blood into the systemic circuit, while the right ventricle pumps it into the pulmonary circuit (Chapter 6). The flap valve separating an atrium

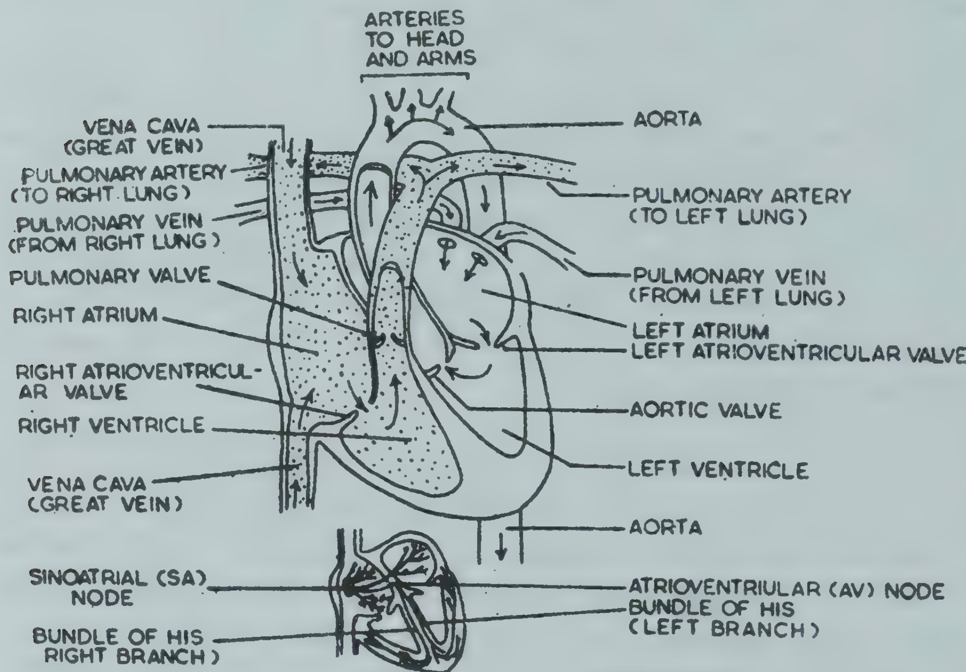

Fig. 10 Structure of the human heart. The heart has been slit open to expose the various chambers, valves and openings of large blood vessels. In the small diagram below is shown the conducting tissue of the heart. The electrical impulse, generated rhythmically by the sinoatrial node travels to the atrioventricular node, bundle of His and its two branches.
(Adapted, by permission, from Weller, H. and Wiley, R. L. Basic Human Physiology. 1979. Fig. 7.6, p. 119.
Courtesy : D. van Nostrand Co., New York, U. S. A.).

from the corresponding ventricle allows the blood to flow only from the atrium towards the ventricle. Similarly the opening of the ventricle into the blood vessel into which it pumps the blood is also guarded by a valve so that the blood does not flow back from the blood vessel into the ventricle. Oxygenated blood leaves the lungs in the *pulmonary veins* (there are four of them) to reach the left atrium. From the left atrium, the blood enters the left ventri-

cle. The left ventricle pumps it into the largest artery of the body (the aorta), which divides repeatedly to distribute the blood to capillaries all over the body.

After the exchange of substances has taken place in the capillaries, the blood from the whole body is ultimately collected in *two large veins* which bring it back to the right atrium. The right

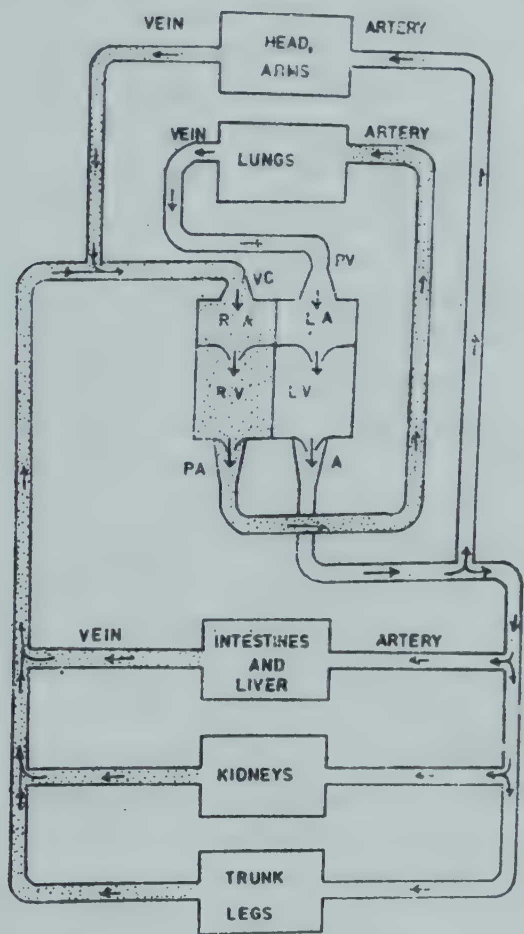

Fig. 11 The systemic and pulmonary circulation. Stippled 'blood', deoxygenated blood; clear 'blood', oxygenated blood.

atrium passes on this blood to the right ventricle. The right ventricle pumps the blood into the *pulmonary artery* which carries it to the lungs where it is made ready for going to various parts of the body. It returns to the heart via the pulmonary veins, and thus the circle is completed (Fig. 11).

The first to work out this circle was William Harvey the English physician who published his findings in 1628. What we have learnt in the last few pages was said by him in a book having seventeen chapters. Apart from the fact that he described in detail all the experiments which had led him to these conclusions, his verbosity is a tell-tale account of the atmosphere of his times. Those were the days when the stifling influence of authority had just started giving place to reason. That is why, to have some hope of having his viewpoint accepted, he had to do a lot more experiments than were sufficient. He had to wait a lot before he had the courage to go to print, and his presentation is a masterpiece in completeness and power of argument. His apprehension is best illustrated in his own words: "... not only do I fear danger to myself from the malice of a few, but I dread lest I have all men as enemies, so much does habit or doctrine once absorbed, driving deeply its roots, become second nature, and so much does reverence for antiquity influence all men". Fortunately, however, he had the satisfaction of seeing his work recognized during his life time.

So far the function of the heart has been outlined only vaguely. What it means in more scientific terms is that the heart provides a pressure head for the movement of blood. Blood, or any other fluid, moves from a higher pressure to a lower pressure. The ventricles pump blood into the arteries at a high pressure. The pressure in the arteries is higher than that in the capillaries; therefore, the blood moves towards the capillaries. On the other hand, the pressure in the capillaries is higher than that in the veins. Therefore, from the capillaries the blood moves into the veins.

The pressure in the blood vessels depends not only upon the force with which the heart pumps the blood but also the diameter of the blood vessels. It is easy to imagine that the smaller the diameter, the higher will be the pressure in the blood vessels. So, if the lumen of the arteries gets narrowed by the deposition of some substances on their inner walls, the pressure in the arteries would rise. This is what is called 'high blood pressure'. It generally results from the deposition of fatty substances in the arteries. Apart from the hereditary tendency for the formation of these deposits, overeating, lack of physical work, prolonged mental worries, drinking and smoking seem to accelerate the process of deposition. High blood pressure harms the body mainly in two ways:

1. Narrowing of the arteries reduces the blood supply to many important organs like brain and kidney, and even the heart itself. This impairs the function of these organs.

2. High pressure in the arteries makes it necessary that the left ventricle pump the blood into them at still higher pressure. That, as we have seen, is necessary to maintain the flow of blood. Again, that, in turn, implies more vigorous contraction of the heart. Pumping hard imposes a strain on the left ventricle, and in the long run, on the entire heart and circulatory system, leading to impairment of the function of the heart.

The movement of blood within the heart is also in accordance with the slope of pressure. Blood flows from the veins into the atria while they are empty and relaxed because during this phase, the pressure in the atria is lower than that in the veins. During the same phase, the ventricles are contracting to pump the blood into the arteries. After ejecting a part of the blood into the arteries, the ventricles start relaxing. So the pressure in the ventricles falls. In the meantime, the atria fill up, and consequently their pressure rises above the ventricular pressure. As a result, the valve between the atria and ventricles is forced open. The flow of blood into the ventricles, and their subsequent contraction raises the pressure in the ventricles above that in the atria, thus snapping the atrio-ventricular valves shut, and stopping the flow. Further ventricular contraction raises the pressure within their cavity even above that in the arteries, forcing open the intervening valves and resulting in a flow of blood into the arteries. The initial gush of blood from the left ventricle into the aorta gives rise to a wave which is transmitted to all the arteries. This wave is commonly looked for at the wrist, and is called the pulse. Since each pulse beat corresponds to a ventricular contraction, the rate at which the pulse is felt gives the heart rate, and its character reflects the 'character' of the heart beat. The pressure relationships outlined above can now be studied even on conscious human beings by introducing a fine polythene tube (catheter) into a vein, and pushing it further and further in till the catheter reaches the heart. By connecting the catheter to a pressure measuring device, one can measure the pressure in that part of the heart where the tip of the catheter is located.

In short (Fig. 10), the heart beats in a definite sequence. First,

the atria relax to fill up while the ventricles contract to send their contents into the arteries; then the atria contract to send their contents into relaxed ventricles. The orderly sequence of contraction is due to the presence of a specialized tissue in the heart, called the *conduction* tissue. It conducts an impulse of activity, electrical in nature, from the atria to the ventricles. When the electrical impulse reaches a chamber of the heart, contraction of the chamber follows immediately. The rate at which the impulse is carried varies in different parts of the heart. The impulse spreads within the atria or within the ventricles very fast, so that both the atria, or both the ventricles, contract almost simultaneously. But at the junction of the atria and the ventricles the impulse is delayed considerably. That is why the atrial and ventricular contractions are not simultaneous. The origin of the impulse of activation is in a small region in the right atrium called the sino-atrial node (S–A node). Impulses originate in the S–A node rhythmically, and are conducted to both the atria and the ventricles by the conduction tissue. Thus the rate at which the heart beats is determined by the rate at which the S–A node generates the impulse. Since the S–A node sets the pace of the heart, it is called the pace maker of the heart*.

In some disease states, the impulse cannot be transmitted from the atria to the ventricles due to a block in the conduction tissue. Such a condition is called *heart block*. In heart block, then, the S–A node cannot set the pace of the heart. The atria continue to beat at the rate at which the S–A node fires. But the impulse of atrial activation cannot pass to the ventricles. Therefore, the ventricles beat out of tune with the atria at their own characteristic rate which is much slower than the S–A node discharge rate. In such cases, sometimes it becomes necessary to supply artificial electrical impulses to the ventricles to keep them beating at the usual rate. Instruments used for this purpose are also called pace makers. Some pace makers discharge continuously at a fixed rate, or at a rate that can be adjusted, while others discharge only when needed. These are called 'demand' pacemakers. The

*The pacemaker is loosely comparable to the engine of a train. The wagons follow the engine, and their speed is determined by that of the engine. Not only that, if some of the wagons were replaced by engines, the speed would be set by the fastest of the engines.

electrodes which actually stimulate the ventricles are made to reach there through a vein, much like a catheter. The leads from the electrodes are connected to an instrument which generates rhythmic impulses. This instrument may be worn like a belt, or it may be implanted in the chest wall by a surgical operation.

We have seen earlier that an electrical impulse precedes contraction. To elaborate a little more, the impulse gives rise to electrical changes in the membranes of the heart cells, which in turn are followed by the mechanical contraction. The electrical changes in individual cells are extremely weak, but the changes in many cells put together are strong enough to reach the surface of the body. They can be picked up by electrodes placed on the limbs or chest, and if suitably amplified, can be recorded on a paper. Such a record is called an electrocardiogram (ECG), and has the configuration shown in Fig. 12. The configuration is

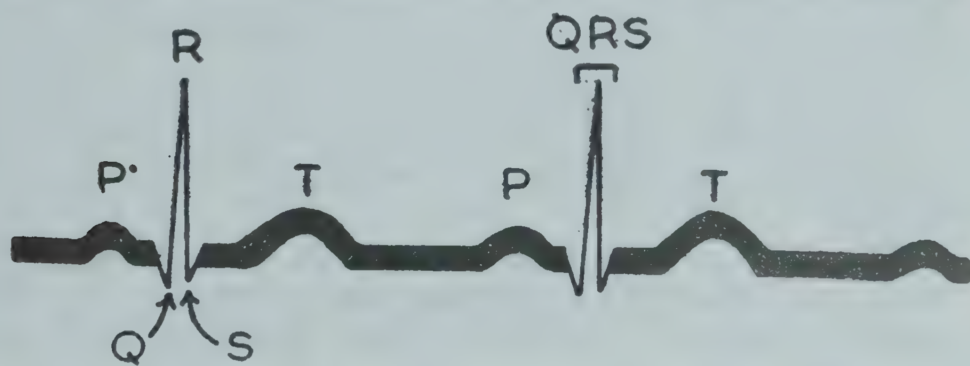

Fig. 12 The configuration of a normal electrocardiogram (ECG). Each P-QRS-T waveform represents one heart beat.

altered in many disorders of the heart, and is, therefore, valuable to the doctor as a diagnostic aid.

The effectiveness of the heart as a pump can be assessed by the amount of blood pumped in unit time. This quantity is called the cardiac output, and is the product of the heart rate and the amount of blood pumped with every beat. The situation may be compared to walking, where the distance covered would depend upon the rate at which the steps are taken, and the length of each step. One can also understand that, beyond a reasonable limit, increasing one of the factors would adversely affect the other factor. For example, if one tries to walk faster by taking steps more frequently, the steps would also tend to get smaller. Simi-

larly, in case of the heart also, increasing the heart rate beyond 180 per minute does not help in increasing the cardiac output. because the stroke volume starts getting correspondingly smaller. In a normal person each ventricle pumps about 5 litres of blood per minute, which is usually achieved by pumping about 70 ml of blood about 70 times every minute. When the requirements of the body for circulation of blood are increased, as in exercise, each ventricle may pump upto 140 ml of blood upto 180 times every minute, which gives a cardiac output of about 25 litres per minute. Thus the heart utilizes only about one-fifth its maximal capacity while we are at rest.* That is why, mild impairment of the heart's function does not cause any inconvenience at rest and even during mild exercise. In atheletes, the maximal capacity is even more. During their training and practice, the heart muscle gets stronger and the resting heart rate falls. For instance a good athelete may achieve his resting cardiac output of 5 litres/minute by pumping 100 ml of blood 50 times every minute. During exercise, he can raise the cardiac output to even 40 litres/minute by pumping 220 ml of blood (he can do so because his heart muscle is stronger) 180 times every minute (faster than that is of no use).

From the above discussion emerges one more fact ; the rate and force of heart beat do not have fixed and static values. The fluctuation is obvious to all of us from the way the heart starts pounding against the chest whenever we are taxed physically or emotionally. There is a story of a pretty nurse who always subtracted ten from the pulse rate of her male patients, and arrived at the 'correct' rate. How does the heart know when to work harder ? The answer lies largely in the communication systems of the body, the chemical messengers (hormones) and the nerves. These systems will be dealt with later (Chapters 12 and 13). Besides, the heart also has an internal regulation of its own. In exercise for example, more blood is returned to the heart by the contraction of skeletal muscles and the resultant squeezing of the veins. This distends the heart. A distended heart tends to beat faster and harder in an attempt to overcome the distension.

*The reserve capacity to the tune of 80 per cent is not exclusive to the heart. It is found in most parts of the body, including the lungs, liver and kidneys. The general phenomenon is sometimes referred to as physiological reserve.

Diseases of the heart

Diseases of the heart excite popular interest because 'heart attack' is often in the news as the cause of death of many a famous personality. However, all diseases of the heart do not belong to this notorious category. There are three categories of heart disease which are relatively common.

1. Congenital

As the name indicates, these types of heart disease are present right at birth. They are due to defective formation of heart in the mother's womb. In most cases, no cause can be pointed. However, avoiding drugs and infectious diseases during pregnancy may help in reducing the chance of such an accident. Keeping in view the complicated structure that the heart is, it is not surprising that in a few cases it is malformed. What is surprising is how it is so often normally formed.

Some of the babies having a congenital heart disease are born 'blue', i.e. their lips, nails, as well as skin have a bluish tinge. However, many of them do not have any such obvious sign. Therefore, it is necessary that every newborn baby be examined by a doctor for the early detection of any abnormality of the heart. As the child grows up, the heart disease shows up by slow growth and breathlessness while playing.

The treatment of the congenital heart disease is generally surgical wherein an attempt is made to correct any defect in the partition or valve of the heart. Many surgically treated children live quite normal lives..

2. Rheumatic heart disease

This is again a curse that just visits some children, and it is difficult to pin point why it does. It usually starts as a sore-throat—something very common, and usually innocuous. But occasionally, the sore throat is followed by pain and swelling in the joints (arthritis). In some of the children who get arthritis, the heart also gets involved Every child gets sore throat but only a few of them get arthritis, and still fewer get the heart disease. Nobody can tell in advance who will get the heart disease. But the disease tends to run in some families, indicating a genetic predisposition;

and is commoner in poor socio-economic groups, suggesting the role of poor nutrition and/or hygiene.

In rheumatic heart disease, generally the valves of the heart are involved. The passages which they guard may become narrow (stenosis), and the valves may become leaky (valvular incompetence leading to regurgitation). One can help these children by

(i) treating promptly any child who gets joint pains following a sore throat.

(ii) treating a sore throat promptly and energetically in every child who got joint pains or heart disease following a sore throat; and

(iii) treating the heart disease at an early stage.

3. Coronary heart disease

This is the form of heart disease which is more widely known and dreaded. It generally affects individuals of a higher age group, though young persons are not immune.

To understand its genesis, one might start with the fundamental fact that, like every part of the body, the heart is also supplied nourishment by arteries. Blood flow through these arteries is indispensable to keep the heart nourished; the blood bathing the cavities of the heart all the time is virtually useless for this purpose because of the large distance between the blood and the heart cells to be nourished. The arteries supplying blood to the heart are called coronary arteries. Sometimes fatty substances are deposited on the inside of coronary arteries, thereby reducing the supply of blood to the heart. The effects of the reduced supply will be most felt when the requirements are enhanced, as in exercise or emotional upheavals. In such states, a portion of the heart may be damaged, and the person feels pain in the chest. However, any pain in the chest does not indicate heart disease. The pain should be precipitated by exertion or excitement, and should settle down when the precipitating factor has disappeared. Further, the pain gives a choking sensation, giving the patient a feeling as if somebody is sitting on his chest. These points are important to understand because many persons get sleepless nights just because they start getting worried about a pain in the chest which has nothing

to do with the heart. The pain may be muscular in origin, or it may be just 'imaginary'.

The disease process affecting the coronary arteries is similar to that affecting other arteries in high blood pressure (see p. 34). That is why, the two diseases often occur together. Hence the predisposing factors and preventive measures are also similar, and they have already been discussed.

CHAPTER 5

LUNGS : THE LIFE LINE

Blood in the capillaries keeps moving continually towards the veins. Blood flow from the arteries towards the capillaries is kept up by the contractions of the heart. Thus the heart works hard to supply fresh blood to every part of the body. But the effort of the heart would be of little use unless the fresh blood supplied is able to serve the tissues better than the blood which has been pushed out. This is possible only if the incoming blood has more nutrients and less waste products than the outgoing blood. Looking at it a little differently, there should be some points in the circulatory system, where nutrients can be added to, and waste products removed from the blood stream. One of the most important stations of this nature is constituted by the lungs. In the lungs oxygen is added to and carbondioxide is removed from the blood.

The general arrangement

Air enters the nose and proceeds towards the lungs. In the lungs, some oxygen is removed from the air taken in (inspired air), and some carbon dioxide added. Then the air returns to the nose and is expelled out (expired air). Because both the inlet and the outlet are at the nose, the entry and exit of air have to alternate with each other. They cannot go on simultaneously. The situation is comparable to a single door bus where the passengers cannot enter and leave simultaneously. That it why, it has been said by Anthony Smith that the lungs have a poor design which has been executed brilliantly. We have talked of poor design : the brilliance of the execution will become apparent when we come to the process of gas exchange.

The air conditioners

Before the air enters the lungs, it has to pass through the nose

and a tree of airways—the bronchial tree (Fig. 13). The trunk of the bronchial tree (trachea) is in the front of the neck and can be felt through the skin. The trachea has a series of rigid rings around it,

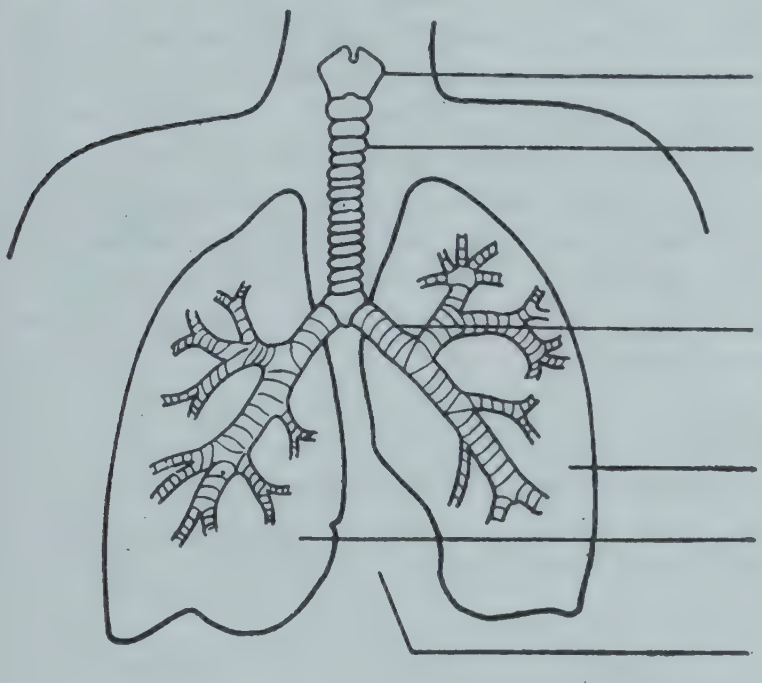

Fig. 13 The respiratory airway tree and lungs.

which can also be felt. Such rings are also present in all the large branches of the bronchial tree. They make the airways non collapsible, while leaving them flexible. The nose and airways do not serve only as conduits. They also warm, humidify and cleanse the air before it reaches the lungs—a treatment akin to air conditioning. Preliminary cleansing of the air is done by the hair at the entrance to the nose. They strain out any coarse particles or tiny insects that may be swept in with the air flow. Finer cleaning is done deeper within the nose and airways by subtler devices. First, the path of air through the nose is tortuous and moist. Both these factors make the probablity of dust particles getting trapped very high indeed. Second, the airways are lined by cells which are moist and have minute hair-like processes (cilia) capable of rowing back and forth. They keep beating in a direction opposed to the direction of air flow so that any particles that have escaped all the traps laid for them are beaten back.

As a result of these mechanisms, the air generally enters the lungs in an amazingly clean state. But unfortunately the air in coal mines and industrial areas overwhelms even these well designed mechanisms. Therefore, the lungs of coal mine workers, and of city dwellers, particularly smokers, keep getting a moderate dose of particulate matter and gradually get blackened due to the accumulation of these particles. Sometimes it is not just the industrialization, but also our own habits to blame. Many of us refuse to use all our cleansing mechanisms by breathing through the mouth. The mouth does not possess the contraptions for cleansing the air. Therefore, except when it is impossible to breathe through the nose, as in a nose-block, it is undesirable to breathe through the mouth.

Breathing in and out

Breathing in is called inspiration and breathing out is called expiration. What moves the air in or out ? The question appears complex but the answer is based on very simple mechanisms. Two basic principles are involved.

(i) As the space occupied by a fixed amount of gas* decreases, the pressure exerted by it increases, and vice–versa.

(ii) Gases flow from a higher pressure to a lower pressure.

Both these principles may be illustrated by an example. Consider two interconnected balloons A and B with provision of a clamp for occluding the link between them whenever desired (Fig. 14). To start with, let them both be inflated to a moderate pressure while they are connected with each other (1). Then, let the clamp be used to occlude the connection (2). Let balloon A be sequeezed with the hand. As the air contained in it is forced to occupy a smaller volume, the balloon can be felt to harden, i.e. the pressure within it increases. Thus a *decrease in volume leads to an increase in pressure*. If the balloon A is kept compressed and

*Gases are the most loosely arranged form of matter. They neither have a fixed shape nor volume. Air is principally a mixture of two colourless, and therefore invisible gases—Oxygen (20%) and Nitrogen (80%). Nitrogen does not participate actively in the respiratory process, but makes air safe. Oxygen is a supporter of combustion, and if air were to be made only of oxygen, fires would destroy everything on earth, including ourselves.

the clamp released (3) some gas would leave balloon A to enter balloon B. This happens because the gas in A is at a higher

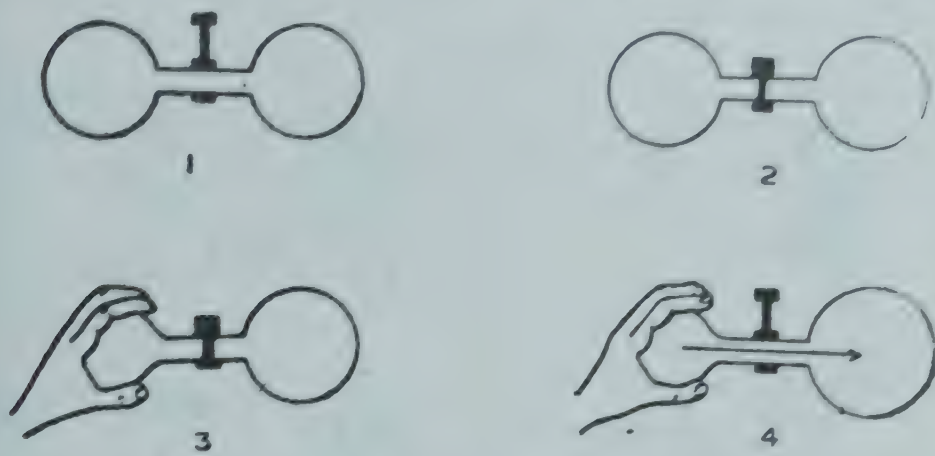

Fig. 14 A simple mechanical model made up of two interconnected balloons to illustrate some physical principles underlying flow of air in the respiratory system. Details in text.

pressure, than in B. *Thus gases move from a higher pressure to a lower pressure.*

Now let us see how these principles operate to bring about inspiration and expiration. If we observe the movements of our chest (thorax) and belly (abdomen) carefully, we would find that during inspiration, they both expand. The chest expands by the upward movement of the ribs and breast bone (sternum). The ribs being curved in a characteristic fashion, their upward movement expands the chest sideways : the process has been compared to the movement of a bucket handle (Fig. 15). The upward movement of the sternum expands the chest from front-backwards; the process has been compared to the movement of a pump handle (Fig.15). The other major movement of inspiration involves the downward movement of the muscular dome-shaped partition between the thorax and the abdomen, called the diaphragm. This movement enlarges the dimensions of the chest from above downwards. Simultaneously, this movement of the diaphragm also pushes the abdominal contents down, thereby making the belly bulge. In short, as a result of the movement of the ribs and diaphragm, the thorax enlarges in all its dimensions. Increase in the volume of

gases within the chest decreases their pressure below the atmospheric pressure. As a result, air from the atmosphere rushes into the chest through the nose.

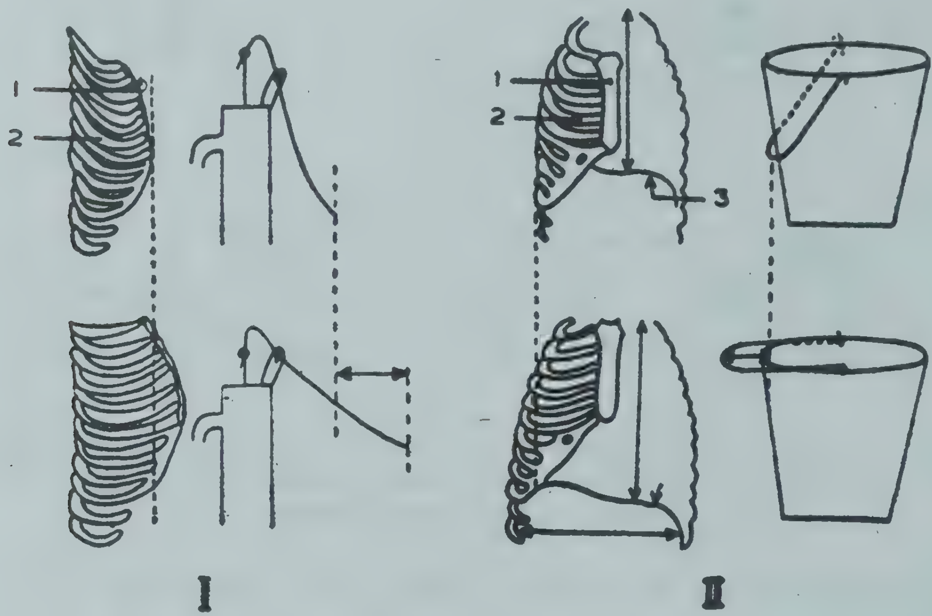

Fig. 15 Chest excursions during inspiration and expiration. I, 'pump handle' movement; II, 'bucket handle' movement. 1, sternum (breast bone); 2, ribs; 3, Diaphragm

During expiration, the events of inspiration are reversed. The volume of the chest decreases and the pressure within it rises above the atmospheric pressure. This results in expulsion of gases from the chest into the atmosphere.

While breathing at rest, normally inspiration is active while expiration is passive. However, when breathing activity is increased as in exercise, or when breathing is difficult due to a disease, both inspiration and expiration may need active effort.

The relative participation of ribs and diaphragm in breathing depends upon habit and habiliment. Preferably, the garments should be loose around the chest as well as abdomen, so that both are free to expand. In pregnant women, breathing tends to be thoracic for obvious reasons.

Mechanisms of gas exchange

The air in the lungs is not really within the body unless it reaches the bloodstream. The transfer takes place in the terminal

portions of the airways. The fine terminal airways balloon out into a cluster of thin walled air sacs which end in tiny air cells (alveoli) (Fig. 16). The wall of an alveolus is made up of only a single layer of very thin cells, and is covered with a tracery of capillaries. A man has about 600 million alveoli. If the entire alveolar surface available for gas exchange were spread out, it would occupy about 600 square feet—the area of a tennis court. The exchange of gases between the alveolus and the capillary is governed by the physical

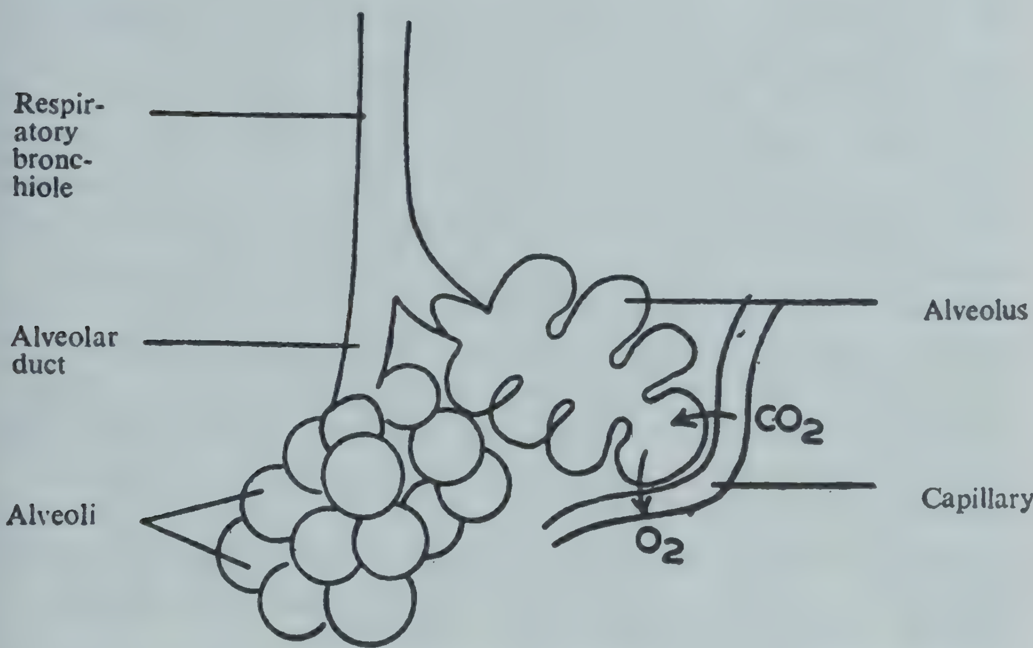

Fig. 16 The gas-exchange unit of lungs. The respiratory bronchiole leads to alveolar sacs, each resembling a bunch of grapes. The alveoli are in intimate contact with capillaries of the lung. Oxygen is passed on to the capillaries, and carbon dioxide is collected from them.

principle enunciated earlier, viz. that the gases move from higher to a lower pressure. Here we further have to keep in mind that the principle applies also to individual gases in a mixture of gases. Since the tissues consume oxygen from and add carbon dioxide to the blood, the blood flowing into the lungs has oxygen at a lower pressure and carbon dioxide at a higher pressure than in the alveoli. Therefore, oxygen moves from the alveoli into the blood and carbon dioxide moves out of the capillaries to enter the

alveoli. The oxygenated blood then returns to the left atrium of the heart to be pumped to the various parts of the body.

Regulation of breathing

It is an everyday observation that the breathing activity increases whenever the body uses up more oxygen and produces more carbon dioxide, as in exercise. How do we manage to breathe with a vigour that is necessary and just sufficient to keep pace with the requirements of the body ? All the answers to this question are not known but some of the mechanisms involved are fairly well understood. These mechanisms are principally situated in the blood vessels or in the brain, where oxygen and carbon dioxide concentrations of blood are sampled. In any case, the information is ultimately fed into and processed by the brain. The output of the brain is in the form of instructions to the respiratory muscles to work with a specified strength and frequency. The common feature of these regulating mechanisms is that they are triggered by excess of carbon dioxide or lack of oxygen. These triggers induce an increase in the rate and depth of breathing. In other words, respiration is stimulated by those changes in the composition of the blood which occur whenever respiratory activity is less than that warranted by the body's requirements. Increased respiratory activity brings in extra oxygen and washes off carbon dioxide, restoring the gases to their normal levels.

Normally the mechanism is so adjusted that a steady state is reached soon which is characterized by absence of quick changes in respiratory activity, and the cyclic changes in gas level are also negligible.

The involuntary control of respiration outlined above saves us the botheration of worrying about our breathing, no matter how busy or careless we are. It can be demonstrated by holding the breath. Since the body continues to use oxygen and produce carbon dioxide, breathholding leads to depletion of oxygen and accumulation of carbon dioxide. Both these factors being strong stimuli for vigorous breathing, there eventually results an uncontrollable urge to resume breathing. To commit suicide by holding the breath is well nigh impossible.

Besides the involuntary control of breathing which operates all the time, we can also superimpose voluntary control on our breathing. We can hold our breath or vary our rate and depth of breathing whenever we feel like it. Wilful modulation of breathing activity forms one of the most important aspects of swimming, singing and many athletic exercises.

CHAPTER 6

FOOD : THE FUEL AND THE FRAME

All of us have to eat in order to live, even if we do not believe in living to eat. Eating is an act we repeat several times a day, day after day; but in spite of it, or perhaps because of it, we seldom pause to think seriously the purpose of this endless exercise. However, it is easy to guess the functions of food. First, it

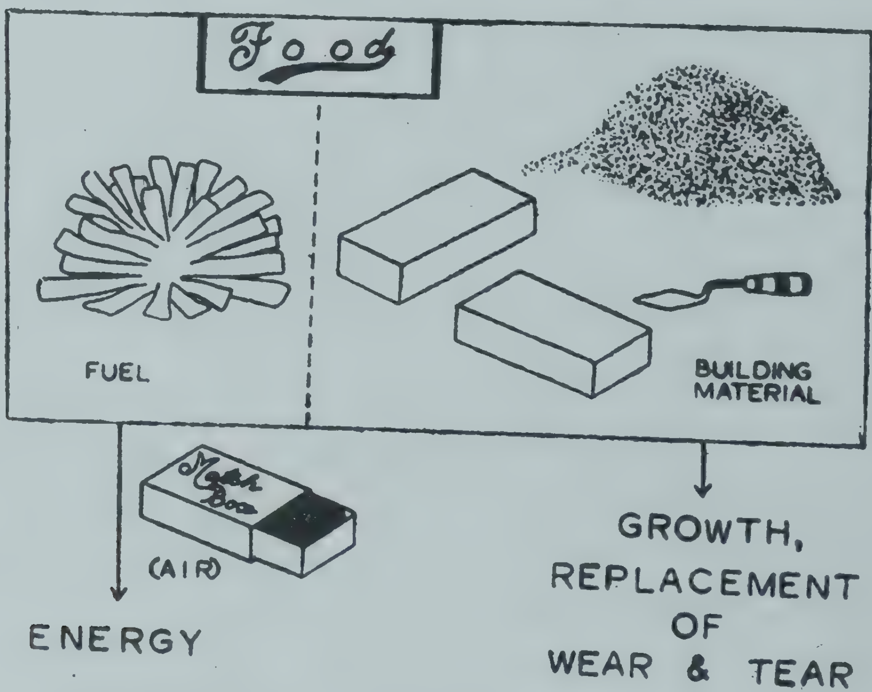

Fig. 17 The functions of food. Food serves as fuel which the body burns for obtaining energy. Oxygen in the air is necessary to burn it, just as a match is needed to light ordinary fuel. Food also serves as building material for growth during childhood and for replacement of living matter lost through normal wear and tear.

gives energy. Energy is required not only for work and play but also for activities basic to life itself, e.g. beating of the heart,

breathing, and working of the kidneys, liver and brain. Thus even if there is a patient resting on bed all twenty four hours a day, he would need energy, and hence food. In fact, just staying alive needs about as much energy as hard physical work. In other words, a hardworking man, like a carpenter or a soldier uses about half his food for processes basic to life, and uses the other half for all the work that he does. Another function of food is to form new living matter. New living matter is obviously formed in children and manifests as growth. Although neither as apparent nor vigorous, the process goes on in adults as well for replacement of tissue wear and tear. So, the second function of food is to provide building material for formation of fresh living matter (Fig. 17).

Types of nutrients

The human body is equipped to burn three classes of chemicals for procuring energy. They are carbohydrates, fats and proteins. But for manufacturing new living matter, we need rather more of the proteins. Protein foods are expensive; it is a waste to use them as fuel. Therefore, the diet should be so arranged that the energy requirements can be met from carbohydrates and fats, sparing proteins for building the body.

Starch is the most abundant carbohydrate in the diet. It is obtained largely from cereals and potatoes. Sugar is also a carbohydrate. The body uses part of the carbohydrates to get energy. Some of it is converted into building blocks of proteins, the amino acids. Some carbohydrate is stored as glycogen in the liver and muscles. Surplus carbohydrate can be converted into fat.

Proteins are made up of a large number of building blocks called amino acids. There are only about 20 different amino acids but the number of proteins they make is far greater just as only 26 letters of the alphabet can make so many words. For efficient body building, our food should be able to provide all the amino acids in optimal quantities. Fortunately, the body itself can manufacture more than half the amino acids from carbohydrate and fat sources as well. Those which the body cannot make must come from food, and are called essential amino acids. Animal proteins contain all of them in about the same proportion as the human body, and are therefore, better than vegetable proteins which are usually deficient

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in one or more essential amino acid. However, in a judicious mixture of two vegetable proteins, one component can compensate for the deficiencies of the other and prove as good as an animal proteins (Fig. 18). Cereals and pulses form an ideal combination in this respect. Thus 'Khichri' is not to be dismissed as a food only for the sick, and 'dal-roti' should not be condemned as a food for the poor.

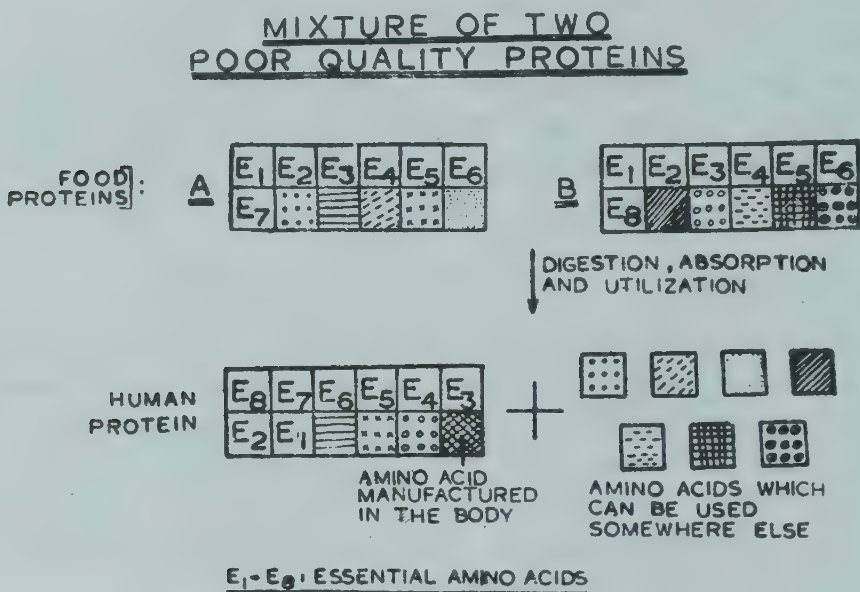

Fig. 18 A properly selected mixture of poor quality proteins can function as a good quality protein. In the hypothetical example illustrated here, we have a mixture of two poor quality proteins, A and B. Protein A lacks the essential amino acid E_8, while protein B lacks E_7. However, the mixture provides the full assortment of essential amino acids, and can therefore be utilised like a good quality protein. In practice, a mixture of cereals and pulses provides such a combination.

Fats are concentrated sources of energy. They improve palatability of food. They delay the emptying of the stomach, so that with fatty meals, the interval between meals can be increased without feeling hungry. They also help in absorption of some of the vitamins. And, of course, they serve as fuel. But in spite of these functions, fats have been found under fire for nearly two decades. The reason is that overconsumption of fats, particularly animal fats has been found to be associated with high blood pressure and heart disease. Vegetable fats have, on the other hand, been found

to exert a 'protective' influence. The relevant difference between the two categories of fats is that animal fats are 'saturated', while in general, vegetable fats have a high degree of unsaturation. However, hydrogenation makes vegetable fats also saturated, thereby depriving them of their 'protective' effect. There is now reasonable amount of evidence to recommend a shift towards consumption of unsaturated vegetable oils (e.g. safflower oil, sunflower oil groundnut oil, corn oil, but not coconut oil). But moderation, as usual. is the best path. There is now some evidence coming up that exclusive consumption of large amounts of unsaturated fats may predispose to biliary stones. Besides, fats in the body come not only from dietary fats, but also from conversion of carbohydrates and proteins into fats. So, if fats are what we are afraid of, we should take care that we do not eat more than we need, for any excess food intake is quickly translated into fats.

To summarize then, proteins are utilized for body building while carbohydrates and fats are used for obtaining energy. The division is, however, arbitrary and not strictly true. Proteins can be burnt down to yield energy, and there is considerable interconversion of nutrients in the body.

Besides, the three energy yielding nutrients, we need water. Indeed, two thirds of our body is water. We also need vitamins and minerals. Vitamins and minerals do not provide energy but are vital participants in chemical reactions going on in the body. One might say that they are not candles but match sticks.

Measurement of food

In order to know whether one is eating the right amount, it is necessary to quantitate the food. Though all food is not utilized to provide energy, for convenience all food is measured in terms of its potential for providing energy. One gram of carbohydrates provides four calories, and so does one gram of proteins. One gram of fats provides 9 calories. A man doing moderate amount of physical work needs about 50 calories per kg of his body weight every day. Children, women and sedentary workers need less calories; those engaged in heavy physical work, and pregnant and nursing mothers need more. More calories for more work applies only to physical work. Mental work needs no additional energy

because brain uses the same amount of nutrients whether it is idling, or whether it is solving complex mathematical problems.

The general principle for further allocation of calories to different nutrients is simple. Let us take the case of a 60 kg man engaged in moderate physical work, and therefore, needing 3,000 calories. He should have, like all adult men and women, a minimum of about 1 g/kg body weight protein That comes to 60 gm protein which would provide him $60 \times 4 = 240$ calories. The remaining 2760 calories should come from carbohydrates and fats. The proportion of these two components can be varied within wide limits, but usual diets would provide about 300-1200 calories from fats and 1600-2500 calories from carbohydrates. Besides adequate proteins and a reasonable mixture of carbohydrates and fats, one should take care to include foods which would supply the necessary amounts of vitamins and minerals.

From chemistry to kitchen

Let us now see how a housewife can use the knowledge presented above to prepare satisfactory meals for the family. Getting down to al' the brass tacks is beyond the scope and capacity of this chapter, but an outline can be presented. Regarding quantity, it is ordinarily quite acceptable, and perhaps desirable, to leave everyone on his or her own unless it is important to gain or lose weight. Qualitatively, it is preferable if the housewife can provide cereal and pulse mixture for the two major meals of the day. How to have this mixture twice everyday without making the diet monotonous will test the culinary skills of the cook. In addition, it is desirable to include some animal protein sometime during the day in the form of milk, curd, cheese, eggs, meat or fish. To provide enough of vitamins and minerals, a green vegetable should be available at the two principal meals. It may be a relief as well as a nutritional bonus to have some of these vegetables uncooked. From the scientific angle, potato is not a vegetable; its composition is closer to that of cereals. Also, from the nutritional viewpoint, fruits and uncooked green vegetable are equivalent.

Not eating well

Although figures from different sources differ widely, according to FAO and World Bank estimates, about a billion persons in the world

do not receive adequate food. In other words, about one fourth of humanity is undernourished. It has been found that the problem is largely one of quantity. If a family is able to afford enough of the locally available and acceptable foods, quality generally takes care of itself. The worst sufferers from food shortage are growing children. Undernourished children are weak and fall repeatedly sick. Illness makes them still more undernourished. Thus a vicious circle is established. If the affected child does not succumb to one of the episodes of sickness, it grows up without realising its full physical and mental potential. As someone has put it very aptly, such children grow up to be paper back versions of the hardcover volumes that they could have been. They grow up to add to the population yet more 'unsound minds in unsound bodies, too unfit to be unhappy or ashamed about it. Marginal malnutrition in adults may not produce serious handicaps, but probably does tell on the general well being and capacity for physical work.

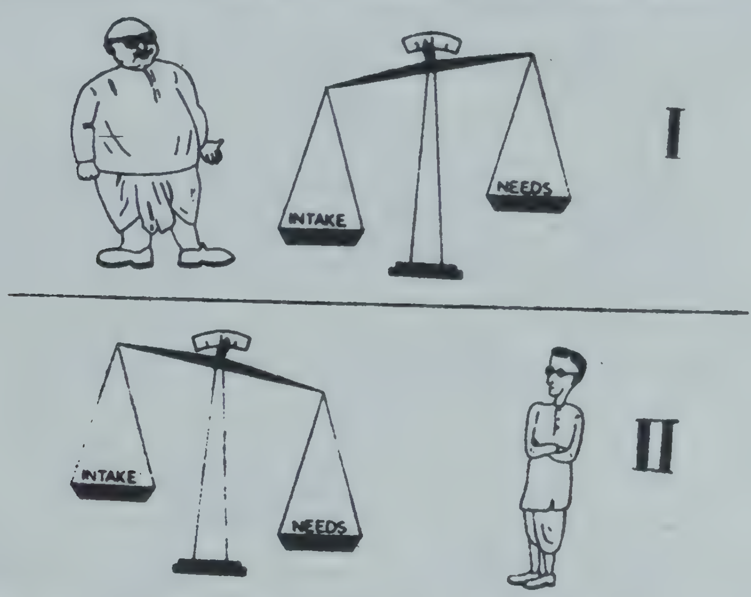

Fig. 19 Weight control is essentially a problem of balancing one's food requirements against the intake. If one of them exceeds the other, the result is abnormal body weight.

The other side of the coin is equally bad. Eating more than one's requirements leads to overweight. Besides looking ugly and being less agile, an obese individual is also more prone to heart disease, high blood pressure, diabetes, joint pains, biliary stones,

and many other diseases. The basic cause of overweight is energy intake in excess of expenditure (Fig. 19). Therefore, the treatment also basically is reducing the food intake and increasing the energy expenditure (through exercise). Energy intake can be reduced somewhat conveniently by cutting down on high calorie foods like fried foods, nuts, chocolate, cake and sweets. To fill the belly while keeping the meal light, one can eat unlimited quantities of raw vegetables and fruits, which provide almost no calories. Further, it has been found that if the same daily caloric intake is distributed into a larger number of meals, it helps in reducing weight. Preventing overweight in children is even more important because once the foundations have been laid wrong, there remains a life-long tendency to put on weight. The ways of preventing and correcting obesity, viz. less food and more work, are available to all. But many do not possess the necessary will power.

CHAPTER 7

PROCESSING OF FOOD

Man does not live by bread alone, but can certainly live by bread. Bread and all else that we eat bears little resemblance to the flesh and blood which it is expected to form. However, if we go in to the chemical composition of food and our tissues, it is found that the basic units constituting both are the same. Therefore, what our body does is to first break food down into its basic compo-

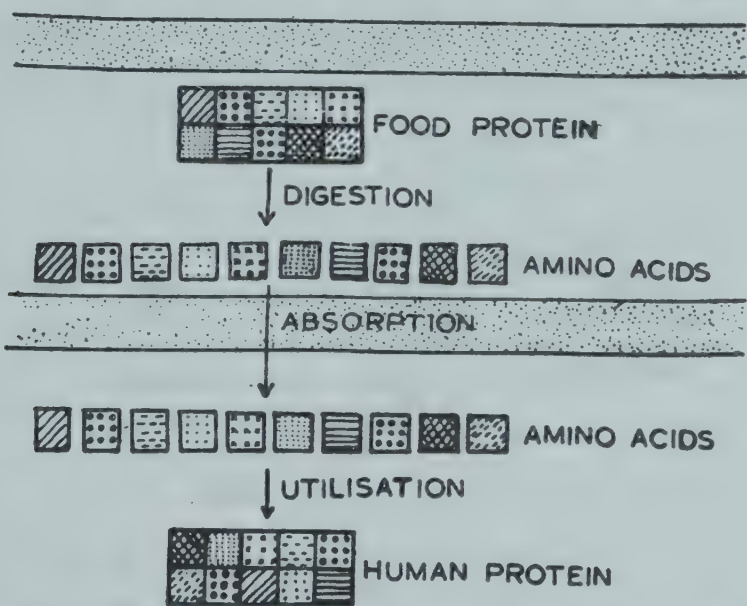

Fig. 20 Digestion, absorption and utilisation. Here the three processes have been illustrated with protein. They are broadly similar for other foodstuffs. During *digestion*, the foodstuff is broken down into simpler products. Then it is taken away from the lumen of the intestine into the blood stream *(absorption*, see also Fig. 24) The absorbed products are *utilised* as building material, as illustrated here, or as fuel (Fig. 17).

nents. This is spoken of as *digestion*. These components are then transferred to the blood stream. This process is called *absorption*.

Since blood travels to all parts of the body, these basic constituents reach every cell. They are picked up and utilised in accordance with the needs of the body (Fig. 20).

The process of digestion and absorption takes place in the alimentary canal (Fig. 21). Alimentary canal is a nine metre long tube extending from the lips to the anus. The processes can be understood by following a morsel of food during the course of its journey through this tube.

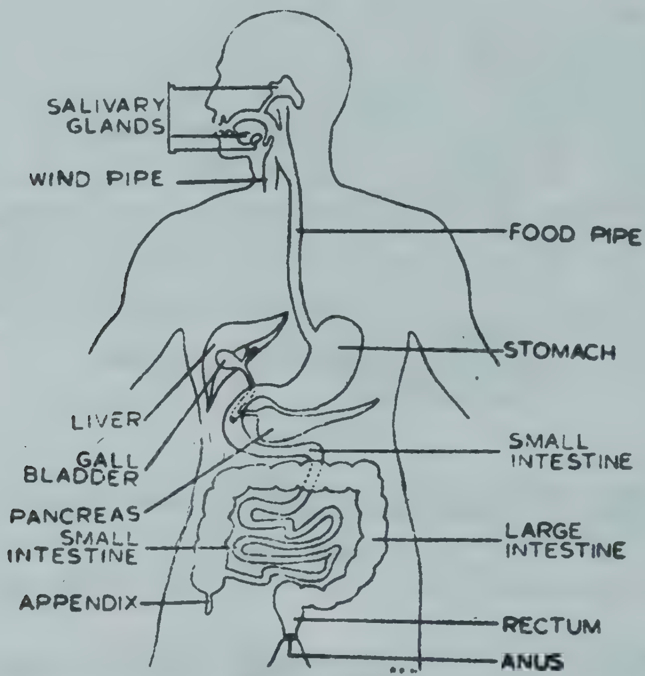

Fig. 21 The alimentary canal.

Mouth : The journey is considered well begun if it starts with a thorough cutting and tearing of the morsel at the entrance. The process of chewing converts the food into fine particles. Chewing is regarded by some to be so essential that they go on chewing a morsel till it becomes almost liquid. While excessive chewing has no scientifically proven value, it is perfectly harmless. At the other extreme are those who lack all emotional attachment to the food and regard eating as a necessary evil. They try to dispense with this chore as fast as their gullet would allow. As usual, both extremes are bad. Moderate chewing is required for

(i) reducing the food to small bits which can be conveniently swallowed.

(ii) breaking the indigestible cell walls of plant cells, so that the digestible contents of the cells can be exposed to digestive juices,

(iii) increasing the surface area over which digestive juices can act,

(iv) allowing time for saliva to act, and

(v) providing satisfaction from food.

While the food is being tossed around in the mouth it also mixes with a watery secretion* called saliva. Saliva is secreted by a set of three pairs of glands situated in and near the mouth. Saliva not only helps make a decent bolus in the mouth, it also inaguarates the process of digestion. It contains an enzyme** called amylase which breaks down the starch in food into maltose. Because of the relatively short stay of the food in the mouth, the digestion of starch is quantitatively not very significant. But, it is important because starch is tasteless while maltose is sweet. That is why food becomes sweeter after being chewn in the mouth for some time. From personal experience we all know that the secretion of saliva is induced not only by the presence of food in the mouth and chewing, but also by mere sight, smell or even thought of food, specially tasty food.

The stay of food in the mouth is terminated by a gentle twist of the tongue which pushes the food to the back of the mouth. After that the food is swallowed rapidly without our conscious will or knowledge. Swallowing involves a series of complicated steps taking place in quick succession. These steps are aimed at preventing the food from entering the airways till it enters the food pipe (oesophagus) (Fig. 22). Occasionally something may go wrong with the smooth and precisely timed steps in swallowing, and food may slip towards the air passage. In that case, coughing comes to our rescue and forcefully chases the food out of the air passages. In an unconscious person, swallowing may not be perfect, and cough

*Secretion is a useful substance discharged by the cells of the body.

**Enzymes are substances, relatively minute quantities of which can increase the rate of a chemical reaction. The enzymes, themselves do not undergo any change in the process. In the present example, what amylase does in minutes, would not happen even in days if starch were just put in water at body temperature.

reflex may be depressed. Therefore, it is dangerous to force water or tea down the throat of an unconscious person in an attempt to bring him round. The drink may enter his air passages and kill him.

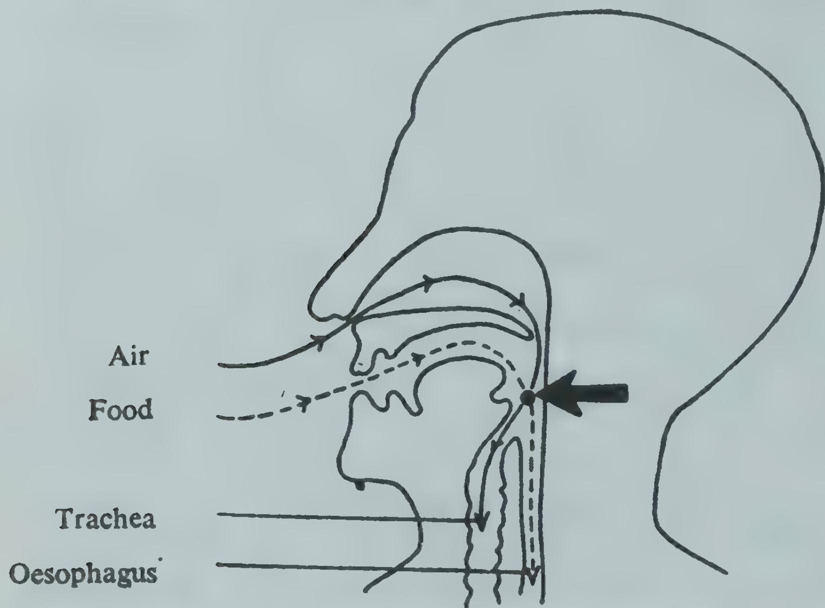

Fig. 22 At the inlet, the food passage (mouth) lies below the air passage (nose). But in the throat, the food pipe (oesophagus) lies behind the wind pipe (trachea). Hence, a criss-crossing of the food and air passages is inevitable (heavy arrow). During swallowing, a number of mechanisms guide the food to the food pipe, and prevent it from slipping forwards into the wind pipe. One of these mechanisms is the rising of the trachea, which can be verified by placing a finger tip on the Adam's apple and then swallowing some saliva. Solid arrows, path taken by air breathed in; dashed arrows, path taken by food.

Oesophagus :

The stay of food in the oesophagus is very brief. The very presence of food in the oesophagus initiates gentle waves of contraction which push the bolus towards the stomach. At the junction of the oesophagus and stomach, there is a zone of high resistance. A momentary let up in the resistance allows the food to enter the stomach. This resistance is useful in preventing the acidic contents of the stomach from entering the oesophagus. The

lining of the oesophagus is not built to stand acid, and is prone to get inflamed if it comes in contact with the acid. This inflammation gives rise to the symptom of 'heartburn'. This may occur occasionally when something goes wrong with the high resistance zone at the lower end of oesophagus.

Stomach

"Some physiologists will have it that the stomach is a Mill, others that it is a Fermenting Vat—others again that it is a Stew Pan—but in my view of the matter it is neither a Mill, a Fermenting Vat, nor a Stew Pan—but a stomach, gentlemen, a stomach". This was the way John Hunter, an eminent British Surgeon of the 18th century, informed his students that nobody really knew what the stomach did. Though a lot still remains to be learned about the functioning of the stomach, today we are not so blank.

Stomach is a highly distensible organ. When empty, it is the size of a fist and lies almost completely hidden behind the ribs of the left side. But at the end of a heavy meal, it may bulge to the size of a foot ball and reach below the navel, which indicates the capacity of the stomach to store considerable quantity of food. This capacity confers on us the convenience of taking meals at long intervals of time even though the body needs a continuous supply of nutrients.

The food in the stomach is homogenized by the gentle mixing waves and is also subjected to the action of an acidic juice. Besides having an acid (hydrochloric acid), the juice also contains an enzyme called pepsin which splits proteins into smaller units called peptides. The acid is important because pepsin can act only in an acidic medium.

We have seen that as more and more food enters the stomach, it stretches itself and gastric juice issues forth from the walls of the stomach. How does the stomach know when to secrete juice, when to stretch or shrink, when to merely mix the food gently, and when to forcefully push it forth ? Well, these activities are initiated and terminated at right moments by the co-ordinating mechanisms of the body—the nerves and hormone. The principal nerve responsible is the vagus nerve. Increase in activity of the vagus nerve initiates the flow of gastric juice in anticipation of the arrival of the food in the stomach, i.e. when a meal has

merely been planned, thought of, seen, smelt or chewn. The vagus nerve also helps continue secretion of the juice, when the food has reached the stomach. When the food enters the stomach, there is also a chemical (hormonal) mechanism which comes into play to augment the flow of gastric juice. The hormone involved is gastrin* which is elaborated by the last portion of the stomach. The secretion of this hormone is stimulated by the presence of food, particularly proteins, in the stomach, and also by the activity of the vagus nerve. Thus all the mechanisms for production of gastric juice are active when the juice is really required. When food is no longer present in the stomach, and more food is not expected, the juice would not be necessary, and the mechanisms responsible for secretion are switched off. Gastric secretion is inhibited not merely by withdrawal of stimuli for its continuation. Entry of food into the small intestine releases another set of hormones which actively inhibit gastric secretion. These hormones are the same which increase the secretion of juices which act on the food in the intestines. Thus nature economises on the hormones by using the same substances to promote secretion where it is required and stopping it where it is no longer required. We shall talk more about these hormones when we discuss the passage of food through the intestines.

We have seen that gastric juice contains pepsin which can split proteins, and also the acid to activate it. The lining of the stomach also contains proteins. Why don't acid and pepsin erode the lining of the stomach ? Many factors appear to save the stomach from the corrosive effects of its own secretions. Firstly, most of the acid and pepsin are secreted only when food is available to be acted upon by them. Therefore, not enough of the digestive juice probably comes in prolonged contact with the stomach.

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*Hormones are substances released directly into the blood stream. They circulate all over the body but produce some effects only in selected target organs. It is ironic that gastrin and other gastro-intestinal hormones also lose themselves in the general circulation and take a circuitous route only to come and act very near the place where they were produced. For instance, the path taken by gastrin is :

Last portion of stomach—veins arising from the stomach—right atrium—right ventricle—lungs—left atrium—left ventricle—aorta—arteries supplying the stomach—stomach.

Secondly, the lining cells (mucosa) of the stomach seem to have specially tough walls which can resist the acid-pepsin attack. Besides, the cells are so tightly packed that the secretions cannot even sneak in through the crevices between the cells. Thirdly, the lining of the stomach is covered with a layer of 'mucus'—a slimy fluid with a weak capacity to neutralize acid. In the past this layer was considered a vital factor in protecting the stomach. But it has been found that it cannot neutralize much acid, and gastric juice can easily penetrate it. Therefore, it is unlikely that mucus offers much protection against erosion. It appears to act mainly as a lubricant. The major protective factor appears to be the cells themselves. In some abnormal circumstances, however the digestive juice may eat away a part of the wall resulting in a peptic ulcer. Peptic ulcer may occur not only in the stomach, but also in the portion of the small intestine immediately adjoining the stomach (the duodenum). The process leading to peptic ulcer may be viewed as an imbalance between acid-pepsin and the mucosal barrier. Either there is too much of aeid-pepsin, or an impaired mucosal barrier, or a combination of both. The next question obviously is, what is it that produces this imbalance ? Overactivity of any of the factors which induce gastric secretion could be the culprit. In practice, it is usually a combination of many factors, some of which have been crisply stated in the triad : hurry, worry and curry. A patient of peptic ulcer is frequently intelligent, ambitious, high-strung, nervous, worried, and often an introvert. His food is often spicy, and he takes plenty of tea and coffee. He may be a smoker and alcoholic.

The other side of the story is impaired mucosal resistance. This happens with aspirin, alcohol, and vinegar. That is why habitual consumption of aspirin to relieve headache can also precipitate peptic ulcer in a susceptible individual. Yes, individual susceptibility differs. There seems to be something inherent in the constitution of some that makes them secrete more acid and/or have impaired mucosal resistance.

The treatment of peptic ulcer is aimed at neutralizing the causative factors. Antacids are given to counteract the acid. Meals are made bland so that the meal excites minimal secretion of gastric juice although it is not certain how far it helps. Small meals are taken frequently so that some food is always present in the

stomach to be acted upon by the juice. Tea and coffee should be excluded from the diet, if possible. If that is not possible, only very weak tea should be taken with milk and sugar. If habituated to smoking and drinking, the patient should try to give them up. Last but not least, the patient should change his attitude to life so that he can take the challenges, failures and disappointments of life lightly.

Acidity is a complaint commonly associated with the stomach and is characterised by sour eructations. Every normal stomach produces acid. But, as we have seen there exists a high resistance zone at the junction of the esophagus and the stomach which does not normally allow this acid to be belched up. It is only when something goes wrong with this safety valve that acid may be brought up leading to sour eructations. Avoiding sour foods can not solve this problem, however. No sour food we eat contains more acid than that produced by the stomach itself. The treatment of acidity is essentially a watered down version of the treatment of peptic ulcer, i.e. small and frequent bland meals, and antacids, if necessary.

Gas is another common complaint associated with the stomach, and many quacks thrive on claims to cure it. The source of gas belched out is usually the air which has been swallowed while eating. Some adults and all infants habitually swallow a lot of air while eating, and then feel like expelling it. Anxious and nervous individuals often swallow a lot more air than is normal. They are also the ones who worry more about gaseous eructations. The more they worry, the more they belch; and the more they belch, the more they worry. Thus a vicious cycle is set up. Such patients just need to be consoled and reassured.

Small intestine

The food, after being digested in the stomach, is transferred, bit by bit, from the stomach into the small intestine. Emptying of the stomach begins 2-3 hours after a meal and is completed during the next couple of hours. Many factors can alter these timings, the most obvious being the total quantity of food taken; the larger the quantity, the longer it stays in the stomach. A factor of practical importance is the quantity of fat present in the food. That fat delays gastric emptying is a fact we frequently

make use of when we can anticipate missing a meal. In that case, we consume more fat at the preceding meal so that the stomach does not empty for a long time and we do not feel hungry.

The first portion of the small intestine which the food enters is called the duodenum. This is an important region because juices from two sources, i.e. pancreas and gall bladder, are discharged into it. Pancreatic juice is a powerful combination containing enzymes for the digestion of carbohydrates, proteins as well as fats. Bile is an essential supplement to the pancreatic enzyme for digestion of fats. Bile emulsifies fats i.e. it breaks down big fat globules into fine droplets of fat, thereby increasing the surface area on which the enzyme can act. The various enzymes in the pancreatic juice and the breakdown products they produce are shown in Table 7.1.

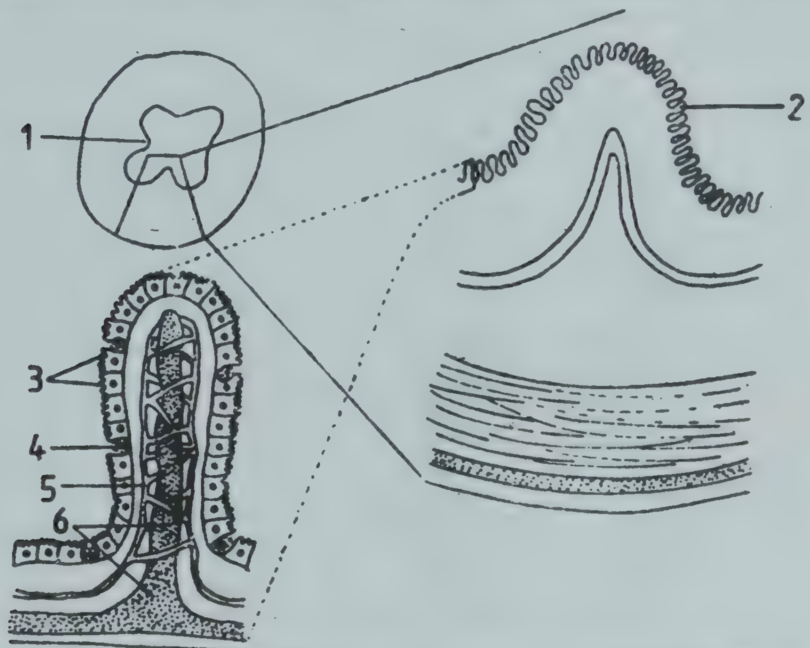

Fig. 23 The surface area of small intestine is enormously increased by repeated folding. Increasing degrees of magnification reveal more and more minute folds.
1, valvulae conniventes; 2, villi; 3, microvilli; 4, goblet cell (see also Fig. 4); 5. blood vessel; 6. lymphatic (for fat absorption). The valvulae conniventes, villi and micro villi increase the surface area of the small intestine three, ten and twenty-fold respectively, giving a total multiplication of 600-fold.

Discharge of pancreatic and biliary secretions into the intestines is under the control of two hormones *secretin* and *cholecystokinin*. The general principle governing these hormones is also the same

as for gastrin; they are there only when required, they do what is needed. Some details about these hormones are also given in Table 7.2. As indicated in Table 7.1, the action of pancreatic enzymes completes the digestion of only fats. The final digestion of carbohydrates and proteins is brought about by the small intestine itself, the enzymes for which are located in minute finger-like processes lining the surface cells of intestines. This ensures that as soon as the digestion is complete, the nutrients are already in the intestinal wall, just one step away from absorption into the blood stream.

Apart from digestion, the main function of the small intestine is absorption. The repeated folds over the surface of the lumen increase the surface area 600 fold (Fig. 23). Thus the structure of the small intestine is eminently suited for its absorptive function. In the process of absorption, digested food is transferred across the

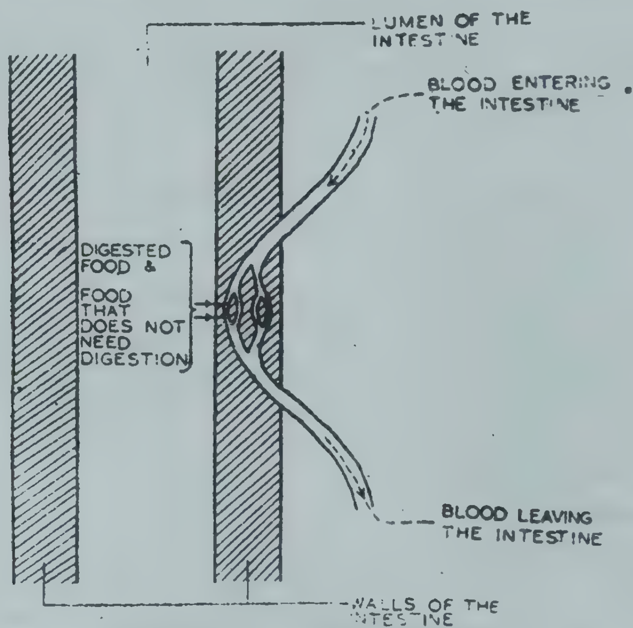

Fig 24 Absorption. During absorption, food enters the blood coming to the intestine and leaves with the blood leaving the intestine. Once absorbed into the bloodstream, food circulates all over the body. It can be used wherever needed.

wall of the alimentary tract (Fig. 24). Food crosses the wall of the small intestine to enter blood vessels in these walls. Thus blood which arrives at the intestine is enriched with digested food

when it leaves. Since blood goes to every organ of the body, the absorbed food also travels to every organ. Hence food which, before absorption, belonged to the alimentary tract, belongs to the whole body after absorption. Food which, before absorption, was essentially outside the body, is truly inside the body after absorption (Fig. 25). The result of absorption is that in the normal individual, by the time the food is ready to enter the large

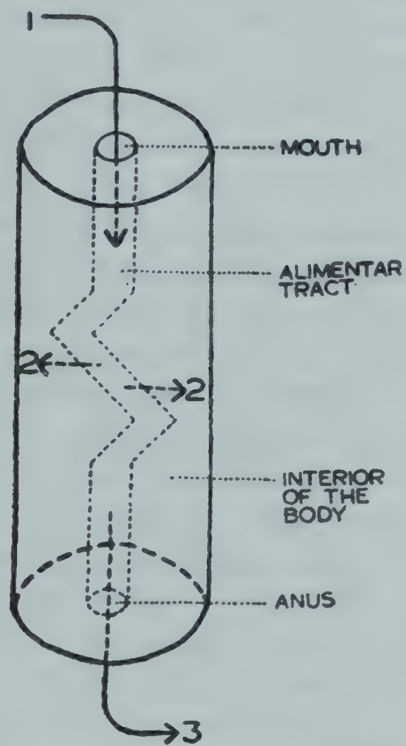

Fig. 25 The alimentary canal is open at both ends. The food that is taken through the mouth (1) is not really inside the body unless it is absorbed (2). Whatever is not absorbed is eventullay lost in faeces (3) and is thus effectively outside the body.

intestine, it contains mainly water, indigestible substances, e.g. cellulose**, and undigested food.

*All foods, except a part of fats, are absorbed into the blood. Most of the fat is absorbed into lymphatics.

**Cellulose forms the cell walls of plant cells. It is a carbohydrate, but cannot be digested by the enzymes present in man. Some animals, like cattle, can digest it. That is why a cow can live on paper while a man cannot.

This is the hodgepodge, mixed with bacteria and the debris of intestinal cells shed into the lumen, that is passed on to the large intestine.

Large intestine (Colon)

The large intestine works hard on the worthless looking legacy that it inherits from the small intestine. It extracts from it almost all the water, and some salts and other nutrients. The absorption of water is an important function. Were it not for the assistance of the large intestine, we would pass a large number of loose watery motions everyday on one hand, and keep busy drinking a lot of water to make up the water loss on the other hand. Besides water absorption, stay of the residual 'food' in the colon subjects it to the action of germs (bacteria) present there. In the process, some of the indigestible food is 'digested' to provide nourishment to the bacteria. Colonic bacteria and man are not merely in a state of peaceful co-existence; they are mutually beneficial. However, the chemical reactions carried out by the bacteria produce gases like carbon dioxide, hydrogen and methane. These gases are passed as flatus. Excess flatus is a minor physical inconvenience but a major social embarrassment. While the tendency to form too much flatus is partly hereditary, everyone affected by it can benefit by avoiding beans, milk and any other foods found to be consistently associated with flatulence. As a result of the work done by the large intestine, its contents become semi-solid. A part of the contents is voided periodically, usually once a day. The basic pre-requisite for the urge to defecate is the presence of sufficient volume of contents in large intestine so that they can exert the necessary pressure in the terminal portion of the intestine (rectum). The other favourable circumstances are the availability of a proper place and atmosphere for the act, and a relaxed mind. A drink, particularly a warm drink, assists the initiation of the defaecation reflex. Long standing habit might have established some other conditions peculiar to an individual, e.g. smoking or reading, which have also to be fulfilled for easy defaecation. Besides, the consistency of the stool should also be soft for a comfortable act.

Considering the above factors, one can visualise the following causes of constipation.

(i) Insufficient bulk in the large intestine. This can be corrected by consuming some vegetables, fruits and coarse cereals. These items contain considerable quantities of indigestible plant material which imparts bulk to the contents of the large intestine.

(ii) Faulty toilet training and irregular habits.

(iii) Excessive concern with the bowels which does not let the mind relax.

(iv) Insufficient water intake, making the stool hard.

To these causes may be added one more, which is, paradoxically enough, frequent purging. A constipated person is usually obsessed with his bowels. Failure to pass motion for a day prompts him to take a laxative. The laxative empties a long segment of the colon much longer than emptied by a normal act of defacation. The result is that the colon does not fill up sufficiently to cause an urge to defaccate the next day. This convinces the individual all the more that he is constipated, and he again resorts to a laxative, which overempties the colon. Thus a vicious circle is established which can be broken by not bothering about the stool for a day or two. This would provide enough time for the colon to fill up, and eventually establish a natural reflex.

Another common disease of the intestines is *diarrhoea*, which is more troublesome and more serious than constipation. Diarrhoea is usually infective in nature, and may be caused by a wide variety of organisms. Some of these infections are susceptible to drugs, while others are not. Be that as it may, the body is able to fight many of the diarrhoeal infections without the aid of any drugs. The most important part of the treatment of diarrhoea, therefore, is not drugs. Rather, it is the prompt and appropriate replacement of the heavy loss of water and salts in the stools. This is particularly important in children where even a small loss forms a substantial fraction of the total salt and water content of the body.

We started our journey with the food entering the mouth. Now that we have reached the other end, hardly anything of the food is left. It has been all badly battered to bits and taken into the blood stream in a systematic, assembly-line fashion. This is an important service rendered by the alimentary tract. Like a faithful servant, the alimentary tract also shares the joys and sorrows of the individual. Therefore, it is only proper not to stuff it with too much, or abuse it with disagreeable foods.

TABLE : 7.1

Region	*Juice*	*Enzyme*	*Enzyme acts on*	*Enzyme action produces*
Mouth	Saliva	Amylase	Starch	Maltose
Stomach	Gastric Juice	Pepsin	Proteins	Protein fragments
Duodenum	Pancreatic juice	Amylase	Starch	Maltose
,,	,,	Trypsin	Proteins & protein fragments	Small protein fragments
,,	,,	Chymotrypsin	,,	,,
,,	,,	Carboxypeptidase	,,	Small protein fragments and amino acids
,,	,,	Lipase*	Fat	Fatty acids and glycerol
Small intestine**	—	Disaccharidases	Maltose Lactose+ and Sucrose++	Glucose and similar substances
	—	Aminopeptidase	Small protein fragments	Very small protein fragments and amino acids
	-	Dipeptidase	2--Amino-acid fragments	Amino acids

*For effective digestion of fats, bile is also required.

**Small intestinal enzymes are located on the surface of the cells of the intestinal wall. They are not secreted into the intestinal juice.

+Lactose is the sugar naturally present in milk. ++Sucrose is cane sugar.

TABLE 7.2

SECRETION			
Juice	*Stimulated by*	*Inhibited by*	*Mechanism of stimulation Inhibition*
Gastric	Thought, Sight, Smell or taste of food; Presence of food in the stomach.	Empty stomach; anger; food entering the duodenum	Stimulated by vagus nerve & gastrin. Inhibited by secretin & cholecystokinin
Pancreatic	Presence of acid and food in the duodenum.	Absence of stimulating factors	Stimulated by secretin & cholecystokinin
Bile	Presence of fats in the duodenum	Absence of stimulating factor.	Contraction of gall bladder stimulated by cholecystokinin.

CHAPTER 8

KIDNEYS : THE FASCINATING FILTERS

Kidneys are often described as bean shaped; on the other hand a popular variety of beans is called kidney beans. Either of these

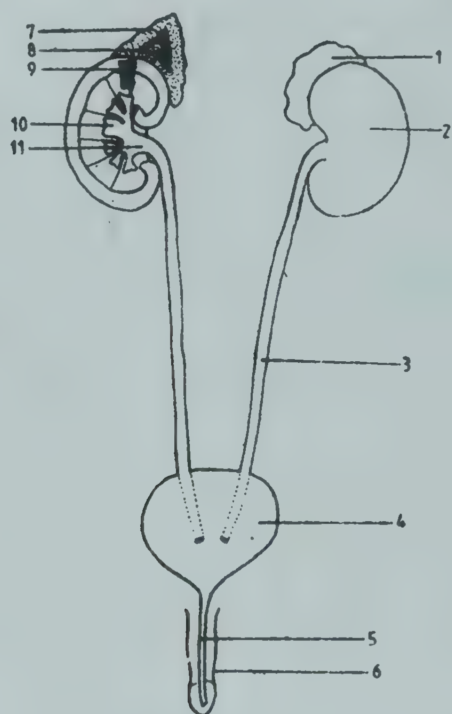

Fig. 26 The excretory system of the male. The adrenal glands have also been shown, although they are a part of the endocrine system. The right kidney and adrenal have been cut open to show some structural details.
1. adrenal gland; 2. kidney; 3. ureter; 4. urinary bladder; 5. urethra; 6. penis; 7. adrenal cortex; 8. adrenal medulla; 9. nephron; 10. calyx; 11. pelvis of the kidney.

expressions can be considered more appropriate according as one is more familiar with beans or kidneys. We have two kindeys situated in the abdomen, nearer the back than the front. They form urine continuously, and conduct it via the *ureters* to the *urinary bladder* (Fig. 26). The bladder has considerable capacity for storing urine. When its contents start approaching its storage limit, we feel an urge to pass urine. Provided that the circumstances are appropriate, we give vent to the urge; otherwise we suppress it till a suitable opportunity presents itself. The urine passes from the bladder to the exterior through a narrow tube called the urethra. The

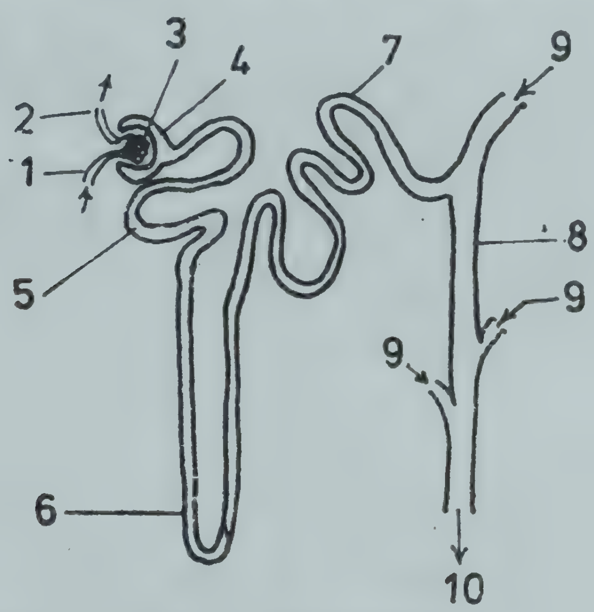

Fig. 27 Schematic representation of a nephron.
1. afferent arteriole; 2, efferent arteriole; 3, glomerulus; 4, Bowman's capsule; 5, proximal convoluted tubule; 6, loop of Henle; 7, distal convoluted tubule, 8, collecting; duct; 9, collecting ducts from other nephrons; 10, to calyx.

urethra is about 4 cm long in women. In men, it traverses the entire length of the penis, and is therefore about 20 cm long. Some old men lose part of their control over the bladder, and feel like passing urine rather frequently. This happens because of the enlargement of the prostate gland which surrounds the lower part of the urethra in men.

Structure of the Kidney

Each kidney is made up of about a million long narrow tube-like structures called *nephrons.* A nephron is the structural and functional unit of a kidney. The urine formed by a kidney is the sum total of the urine formed by its nephrons. Each nephron is about 5 cm long, but appears shorter because it is extensively folded up at the two convoluted tubules (Fig. 27). The total length of the 2 million nephrons that we possess is, thus, about 100 km, i.e. more than the distance between Delhi and Mathura. The diameter of the different segments of the nephron varies from 10 to 60μ*.

A nephron essentially consists of a receptacle (*Bowman's capsule*) enclosing a bunch of capillaries (*glomerulus*) like a closed fist. The receptacle leads to a long tubule. The terminal ends of the tubules from different nephrons start converging and coalescing into common tubes, till finally they form just one tube, the *ureter.* The glomerulus and Bowman's capsule form one functional entity. They *filter* the blood. The tubules *alter* the volume and composition of the filtered fluid.

Filtration

To understand the process of filtration, it is necessary to have a close look at the structures involved (Fig. 28). The glomerular capillaries are fed blood by a blood vessel called the *afferent arteriole*, and are drained by a narrower blood vessel called the *efferent arteriole.* By virtue of this arrangement, the pressure in glomerular capillaries is higher than that in any other capillary bed in the body. The pressure also happens to be considerably higher than that in the lumen of the Bowman's capsule. Since fluids move from a higher pressure to a lower pressure, it is possible for fluids to escape from the glomerular capillaries into the Bowman's capsule, provided the intervening membranes have pores to allow the transfer. If the filtration surface is viewed with an electron microscope, we can resolve it into three layers (Plate 4,5,6). One layer is formed by the cells forming the wall of the capillaries. This layer shows punched out holes, about 400—1000

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* $1\mu = \frac{1}{1000}$ millimetre $= \frac{1}{1,000,000}$ metre

A°** in diameter. The next layer is formed by a membrane which has holes only about 100 A° in diameter. The last layer consists of cells which have projections. The projections of contiguous cells fit into one another like a jigsaw puzzle, leaving only small gaps in between. These gaps allow molecules no bigger than about 30 A° to pass through them with ease. In short, the filtration surface may be visualised as a series of successively finer sieves. The final sieve has pores only around 30 A° wide. But it is well to

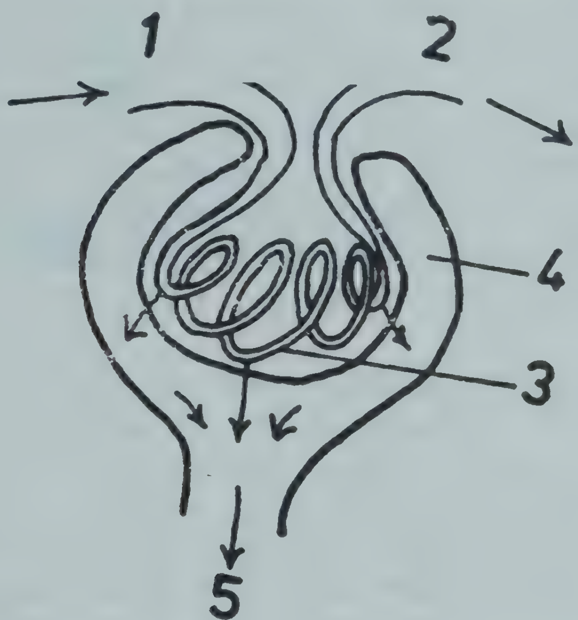


Fig. 28 The glomerulus
1, afferent arteriole; 2, efferent arteriole; 3, capillaries constituting the glomerulus 4, Bowman's capsule; 5, the fluid filtered into the Bowman's capsule passing on to the proximal convoluted tubule.

keep in mind that it is an indiscriminate sieve. It allows every molecule smaller than 30 A° to pass through it. That is why, the fluid formed as a result of filtration (*filtrate*) contains not only urea, which it is desirable to discard, but also a great deal of water, glucose, amino acids and salts that it is not desirable to discard. In short, the filtrate resembles the plasma (Chapter 3) except that it does not contain the plasma proteins.

** $1A^\circ = \frac{1}{10,000}\mu = \frac{1}{10,000,000,000}$ metre

Tubular function

The amount of filtrate formed every day would fill more than 10 buckets. If all this were to be eliminated as urine, one can imagine the amount of water one would have to drink to replace the loss. Further, as mentioned earlier, the filtrate also has numerous other substances which deserve to be conserved. These problems are looked after by the tubules. Before the filtrate becomes urine, the tubules remove from it about 99% of water and almost all the essential solids. Removal of these substances from the lumen of the tubules and returning them to the blood stream is called *reabsorption.* The tubules not only reabsorb substances, they also transfer some substances from the blood stream to the lumen of tubules. This process is called *secretion.* The most important substance secreted is acid. In the course of chemical reactions going on in the body, many acids are produced. By secreting acid, the kidneys help in maintaining the acidity of the body fluids constant.

Thus the final urine excreted is the result of three basic processes : *filtration*, *reabsorption* and *secretion* (Fig. 29). The method adopted by the kidneys for clearing the blood is comparable to clearing a busy table by first removing every-thing lying over it, and then replacing whatever is needed on the table.

The amount and composition of the filtrate formed is rather constant at about 120 ml every minute. Of this, about 85% of water is always absorbed in a normal kidney in the initial portions of the tubule. Glucose and amino acids, being nutrients, are always welcome; so they are also reabsorbed right in the beginning of the tubule. There is, however, a limit to which glucose can be reabsorbed. Normally that limit is never exceeded, and therefore, glucose is completely reabsorbed. But in diabetes, the blood glucose concentration is high. Therefore, the concentration of glucose in the filtrate is also high. It may exceed the capacity of the tubules to reabsorb glucose. In that case, glucose spills over in the urine. That is why the urine of a diabetic is sweet, and it is sometimes the ants that collect around the urine that give a clue to the diagnosis. The glucose in the urine has, in order to stay dissolved, to carry at least a minimal quantity of water with it. That is why a diabetic passes large volumes of urine. To make up for the excessive water loss, he drinks a lot of water. Further,

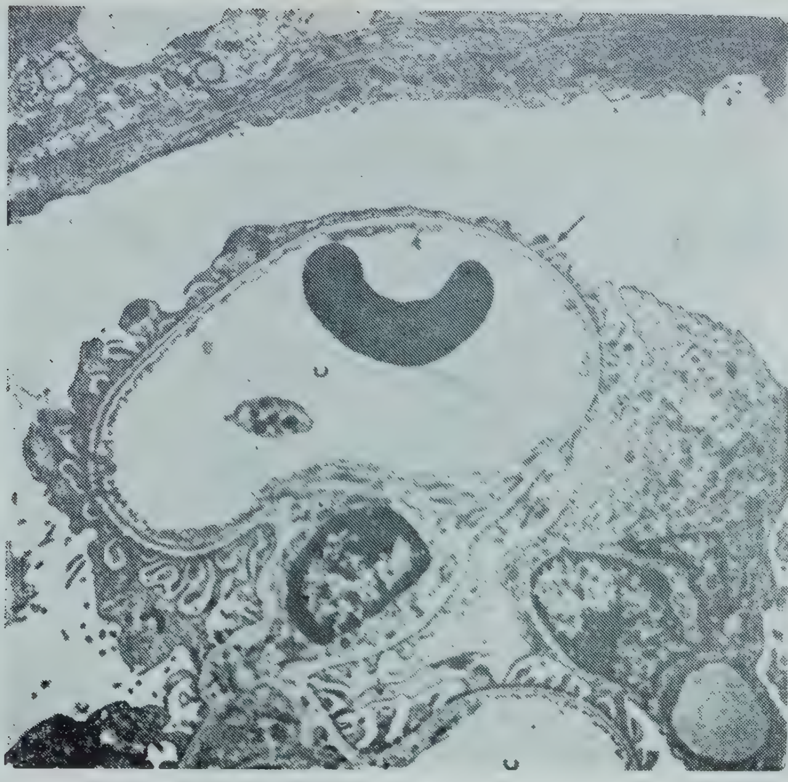
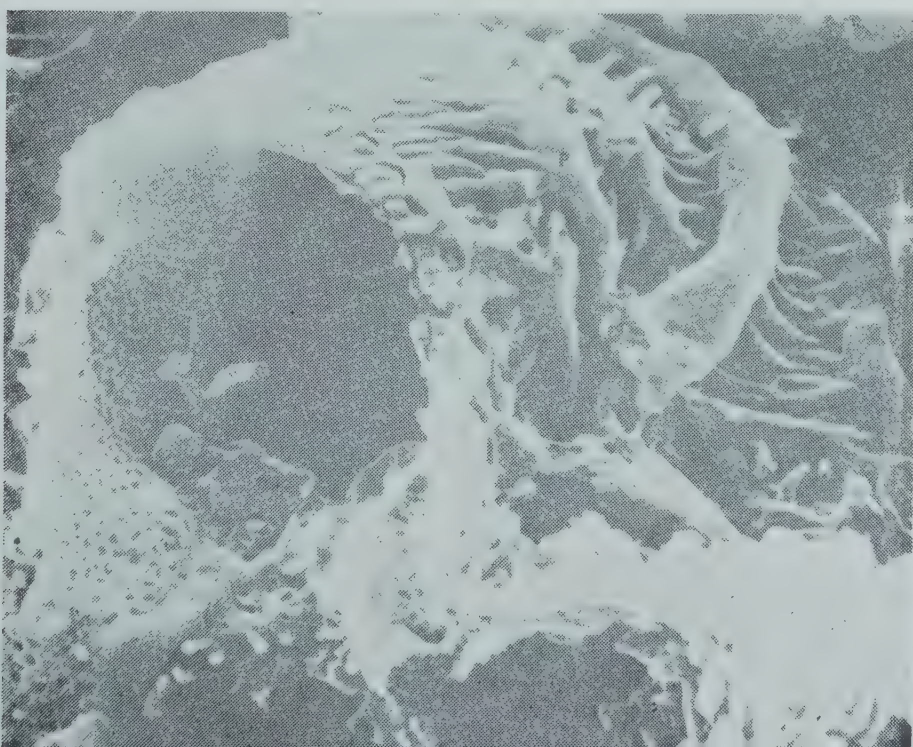


Plate 4. Electron microscopic structure of the filtering surface of kidney. Capillaries (C) lined by a layer of cells. Just next to the lining cells is the basement membrane (BM). Outside the basement membrane are the cells with foot processes, podocytes (P) with their small feet (arrow). (Magnification: 6,100 times).

Plate 5. Scanning electron microscopic picture of a cut capillary loop showing how the foot processes of podocytes (P) interdigitate along the capillary surface. The pores in the capillary wall are seen towards the left. (Magnification: 17,200 times).



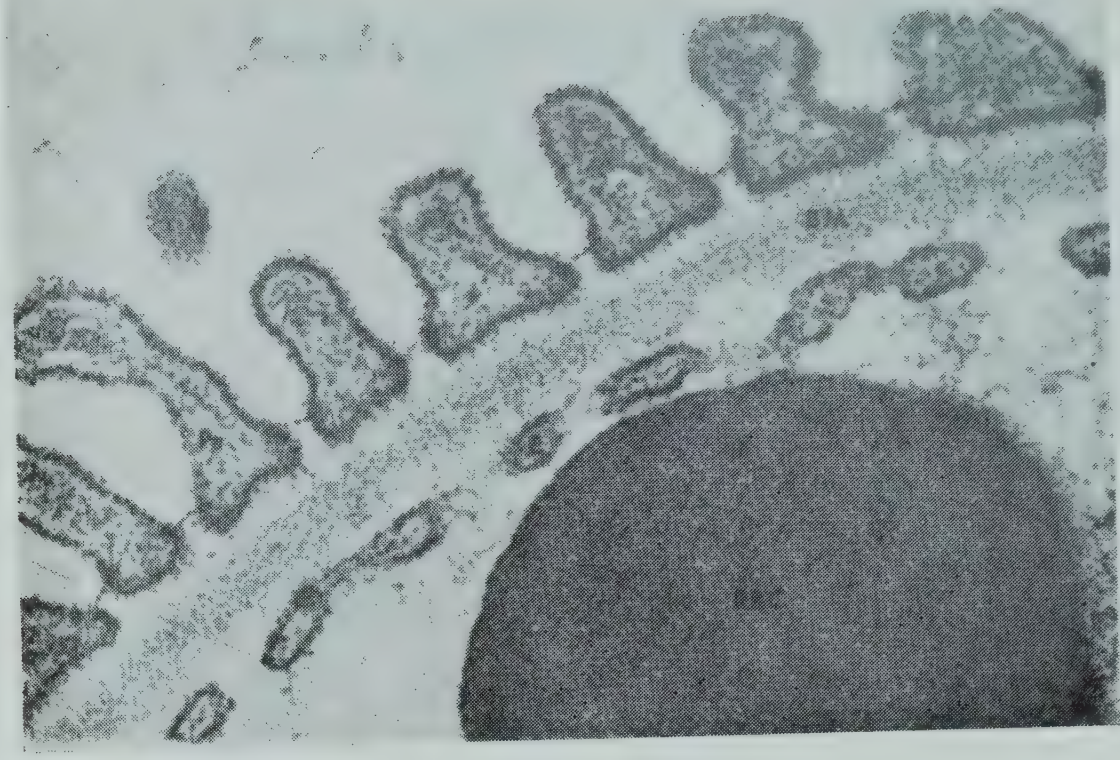


Plate 6. A highly magnified picture showing clearly the three components of the filtering surface: cells lining the capillaries (E), basement membrane(BM) and foot processes (Pe). Also seen is a red blood cell in the capillary lumen (RBC). (Magnification: 71,700 times).
(Reprinted with permission from Weiss L and Greep R O, Editors. Histology: 4th Edition, 1977. Fig. 22-8, p. 839, Fig. 22-10, p.841 and Fig. 22-11, p. 842.
Courtesy: Mc Graw Hill Book Co., New York, U.S.A.).

Plate 7. A patient undergoing dialysis at the All India Institute of Medical Sciences, New Delhi. (Courtesy: Dr S C Dash, Nephrology Unit, AIIMS).

to compensate for the food lost in the form of glucose in the urine, the diabetic eats a lot. Excessive eating (polyphagia), excessive drinking (polydipsia) and too much of urine (polyurea) are the three cardinal symptoms of diabetes.

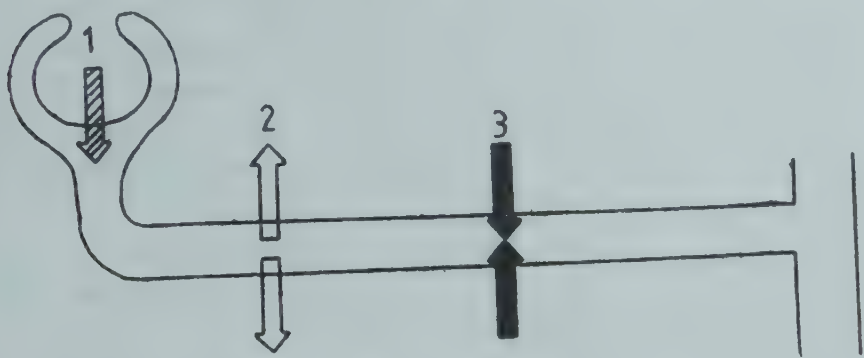


Fig. 29 The basic processes involved in urine formation. 1, filtration; 2, reabsorption; 3, secretion.

The extent to which more water and various other substances are reabsorbed or secreted varies with the requirements of the body. Requirements of water and salts, and production of acids, would depend upon various factors like their intake, production, and loss through other routes. The reabsorption and secretion of these substances in the kidneys is so adjusted that the various cells of the body are bathed in a fluid which is relatively constant in composition. We see an illustration of these facts in everyday life. For instance, in summers we lose considerable water through sweating. To compensate for it, we should lose less water in urine. Accordingly, the urine is smaller in volume and consequently more yellow in colour, indicating that the yellow coloured solids in the urine have been dissolved in a smaller volume of water. If we take exercise in the hot sun and produce additional sweating while restricting our water intake, the urine becomes minimal and very concentrated indeed. Just the opposite phenomenon occurs in winter if we take a couple of glasses of water. How the kidneys know when to do what is again the marvel of the communication systems of the body, viz., hormones and nerves. The kidneys, of course, have to be responsive to the communications they receive from these channels. We shall discuss briefly only two of the major mechanisms involved.

There is a tiny part of the brain called the *hypothalamus*. There is also a part tinier than this which is very sensitive to the concentration of water in the blood. As soon as the blood becomes just a bit more concentrated than normal, this part of the hypothalamus detects the changes before any other cells of the body realize that something has gone wrong. It responds to this change by producing a chemical substance called antidiuretic hormone (ADH). This substance travels in the blood stream to the kidneys and increases the reabsorption of water so that the blood gets a little thinner. In this way, by regulating the release of ADH, this part of the brain keeps the body water constant.

An important mechanism for regulation of salt in the body is located in an organ lying just over the kidney, and therefore called the *adrenal gland*. The fact that it lies close to the kidney is only a coincidence. It functions in just as circuitous a manner as it would if it had been in the neck or the leg. It is sensitive to the salt content of the blood. As soon as the salt (sodium) concentration becomes just a little less than normal, it releases into the blood stream a substance called aldosterone. Aldosterone, upon reaching the kidneys, induces them to reabsorb more sodium, thereby tending to restore the sodium concentration of body fluids.*

There are some chemical substances which can trick the body mechanisms into producing more urine even when, physiologically speaking, the body need not do so. Such substances are called diuretics. The diuretic effect of alcohol and tea is common experience. Alcohol does so by inhibiting ADH secretion. The caffiene, present in tea, acts directly on the kidneys to reduce the reabsorption of water. Some diuretic drugs form a part of the treatment of certain diseases.

The abnormal kidneys

Part of the renal tissue may get damaged by various types of insults. Some disease processes affect the kidneys directly and exclusively. Some others affect blood vessels in general, those

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* Although blood is only a part of the body fluids, the concentration in body fluids and the concentration in blood can be used interchangeably in the present discussion. The reason is that blood and the other fluid compartments of the body have constant exchange going on amongst them. Therefore, a change in one reflects in other compartments also.

of the kidneys included. If the blood supply is affected, renal function is affected. This is to be expected since the entire function of kidneys depends upon adequate perfusion with blood. Generalised diseases which involve the kidneys include high blood pressure and diabetes.

In diseases of the kidneys, it is well to keep in mind that a nephron once lost does not repair itself back to normal. We have to make do throughout life with the nephron population we are born with. But like other vital organs, kidneys also have considerable physiological reserve. One can safely carry on all routine functions with just one kidney instead of two.

Kidneys can get damaged by various types of insuits : germs, 'stones', chemicals, etc. The damage may be sudden and severe in its impact, giving rise to the so called acute renal failure. More commonly, however, the damage progresses slowly, giving rise to chronic renal failure. Damage to the glomerular filter may allow precious plasma proteins to escape in the urine. Damage to the tubules may impair reabsorption of water and salts, resulting in their excessive loss in the urine. Impairment of the acid secreting mechanism may lead to accumulation of acids in the body. Urea, the chief breakdown product of proteins, fails to get excreted adequately, and therefore its concentration in the blood increases. The treatment of these disorders is aimed at making up the excessive losses and reducing the load for the kidneys. When the damage to kidneys reaches a point where these supportive measures cannot sustain life, the only alternatives left are renal *transplantation* or *dialysis* (artificial kidney).

1. Renal transplantation

Transplants of the kidney have been relatively more successful than those of the heart and other organs. Transplants taken from identical twins are the most successful. But such a kidney is only rarely available. In that case, the kidney of any close blood relative or any other donor can be used after appropriate testing for compatibility. Cadaver kidneys taken from individuals who have died less than one hour earlier have also been used successfully.

2. Dialysis (Artificial Kidney)

The so called artificial kidney is based on the simple principle

that substances tend to move from a higher concentration to a lower concentration. But when actually put into practice, it takes a very sophisticated and expensive form (Plate 7). The machine used consists essentially of a membrane which allows the passage of water and other small molecules, but not of plasma proteins or blood cells. The patient's blood is brought to one side of the membrane and a specially designed solution (dialysing fluid) is brought to the other side of the membrane. The dialyzing fluid has all the small molecules in the same concentration as *normal* plasma *except* that the substances, which a patient with renal disease accumulates, are absent. Therefore, when the blood and the fluid are present on the two sides of the membrane, the accumulated substances pass from the blood into the dialysing fluid.

Artificial kidney is useful in acute as well as chronic renal failure. In acute renal failure, it is required periodically for only a few weeks to tide over the period of crisis. During this period, the kidneys recover sufficiently from the acute trauma to take over their normal function. On the other hand, a patient of chronic renal failure has to get dialysis carried out for 12 hours every 3-4 days for the remainder of his life. The cost in terms of men and material is so prohibitive that no country in the world can provide this facility to all its eligible patients. Whom to provide, and whom to deny the facility presents a ticklish ethical problem which is yet to be solved to everybody's satisfaction. Most people agree that, if possible, no patient of acute renal failure should be denied this facility. Regarding chronic renal failure, one commonly expressed view is that young patients, who have a fairly long, productive and useful life to look forward to, should, in general, be given preference for this treatment.

Prevention of renal disease

Prevention is usually simpler and cheaper than cure. Probably it is nowhere more true than in case of kidneys. Most of the diseases of the kidneys are either due to germs, or due to formation of stones. Germs cannot grow in plain water; they need food. Therefore, they grow much better in concentrated urine than in dilute urine. Stones can also form only if some salts crystallize as solid particles, which is possible only in a concentrated solution. Therefore, dilute urine is a safe urine. To make the urine

dilute, all one needs to do is to take plenty of water. This suggestion assumes special importance in the summers of the tropics, when the mercury touches 45°C and profuse sweating is common. Then it takes a very conscious effort to drink water sufficiently frequently. But it is certainly worth the trouble.

Sips of water is what it takes
To keep your kidneys shipshape.

CHAPTER 9

BODY DEFENCES

We are a part of a delicately balanced environment. All living beings depend upon one another, directly or indirectly. Nevertheless, survival is not necessarily a result of peaceful co-existence. Very often it is the result of an exercise for exclusive existence. Human beings can possibly be killed by tigers and snakes. But the mighty enemies of man, really to be dreaded, are the tiny germs or microbes, visible only with the help of a microscope. They are present all around us. There are millions of them in every drop of water that we drink, in every whiff of air that we breathe. In spite of living in such a hostile environment, man as a species, has survived for millions of years; and as an individual, every man can hope to live the biblical three score and ten years. Medicine has very little to do with this miracle. Scientific medicine as we know it today, has been in existence for an infinitesimally small fraction of human history. Further, even at its best, medicine only assists the built-in defence mechanisms of the body which are responsible for this miracle. Unfortunate individuals, whose defence mechanisms are impaired, do not live long in spite of best medical aid.

In a broad sense, every part of the body is also a part of the defence mechanisms of the body to the extent that it contributes to the well-being of the organism. But some organs involved in defence in a rather direct fashion may be mentioned. The eyes, ears or nose give us a clue about an approaching enemy : the muscles enable us to run away from, or put up a fight with the predator. Some mechanisms prevent germs from entering the body, e.g. the skin covering almost the whole body; and the hair and sticky fluid present in the nose. Some others kill the microbes as soon as they enter the body, e.g. acid in the stomach, or the tears in the eyes. Some of the most effective weapons of the body

are however, not so obvious. The present discussion will be centred chiefly around them.

I. Mononuclear Phagocytic System (MPS) or Reticulo-Endothelial System (RES)

This system is a family of ubiquitous cells which have specialised in dealing with germs and foreign particles by eating them up. That is why these cells are called phagocytes (phagein, to eat; cyte, cell). They are present in all tissues but are particularly concentrated in liver, spleen and bone narrow. Monocytes in the blood are the circulating counterpart of these cells. Any microbe or undesirable substance entering the body is sure to run into some of the cells of the MPS. The cells engulf the invader. Once within the cell, the invader is in a spherical space called vacuole (Fig. 30). The vacuole fuses with lysosomes (chapter 2) present

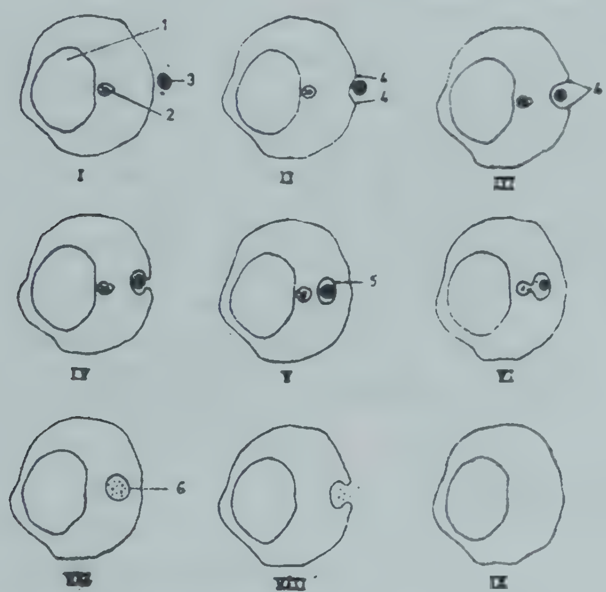

Fig. 30 Phagocytosis.
1, nucleus; 2, lysosome; 3, particle to be ingested; 4, cellular processes (pseudopodia); 5, vacuole containing ingested particle; 6, digested particle; I-IX, stages in phagocytosis.

in the cells. The lyososomal enzymes digest the invader. As in the digestive tract, some of the waste remains of the invader are

expelled from the cell. Nobel laureate Prof. de Duve, a pioneer in the study of lysosomes, has shown that a wide variety of diseases arise from what may be called the 'indigestion', 'constipation' or 'diarrhoea' of phagocytes.

It is apparent that phagocytosis is an important mechanism for combating many diverse invasions. But the process in non-specific, and is devoid of memory, i.e. an encounter with an invader does not make the body better equipped to deal with a subsequent encounter with the same organism.

II. Immune Mechanisms

These are the more fascinating, and also more complicated defence mechanisms of the body, still far from being completely understood. They afford specific protection against specific germs, and are endowed with memory.

Like phagocytosis, the immune mechanisms of the body are also a true defence system; they are never the aggressor. The germs first have to get into the body to activate the immune system. In spite of this handicap, the system works with such rapidity and ferocity that the aggressor is generally overwhelmed. At the first encounter with the aggressor, the response of the immune system is rather slow and week. But at subsequent encounters with the same or similar germs, the response is generally very rapid and vigorous. The response of the immune mechanisms to an invasion can be broadly categorised into two groups :

1. Humoral immunity
2. Cellular immunity

The type of response selected by the body depends upon the nature of the aggressor : the body seems to know which weapon will be most effective for whom. The central organization of both types of responses is in the lymphoid organs of the body. Lymphoid organs are factories for the production of lymphocytes. They include principally bone marrow, thymus, lymph, nodes, spleen and some 'patches' in the wall of the small intestine. Corresponding to the two responses, there are two types of lymphocytes—B lymphocytes concerned with humoral immunity, and T-lymphocytes concerned with cellular immunity.

1. Humoral immunity

Humoral immunity comes into play in response to invading germs, as well as some harmful chemical substances. In some cases, the harmful chemical substances (toxins) are produced by the invading germs. The main feature of the response is the production of proteins (antibodies) which circulate in the blood stream and neutralize or help eliminate the invading agent.

What triggers antibody production ?

Antibody production is usually triggered by a protein called the antigen. The antigen may be, and usually is, only a small part of the invading agent. If this part is identified, separated and introduced into the blood stream, it alone also triggers the antibody response. If the antigenic component of a number of germs is the same, antibodies evoked in response to all of them will be the same. Obviously, therefore, infection by any one of them will afford protection against others also.

How are antibodies produced ?

Upon entry into the body, the antigen first comes into contact with macrophages (phagocytes) in the tissues (Fig. 31). The reaction of the antigen with the macrophage, in some mysterious way, renders it fit for recognition by a T lymphocyte in the blood stream. The circulating T lymphocyte guides the antigen to appropriate B lymphocytes in lymphoid organs. In the presence of T lymphocytes and antigen, the B lymphocytes proliferate and differentiate into antibody forming cells (plasma cells). Plasma cells start manufacturing antibodies specific for the antigen in question.

Theories which seek to explain the synthesis of specific antibodies can be grouped into 'instructive' and 'selective' theories. Instructive theories initially propaged by Linus Pauling (of vitamin C fame) postulate that all plasma cells are alike. It is the antigen that directs the plasma cells to manufacture a specific protein (antibody). Selective theories originally stated by Burnet, on the other hand, assume that there are as many types of B cells as the antigens. The antigen-T cell complex selects the appropriate B cell from a large variety available. The presence of the antigen, according to selective theories, only triggers the proliferation of appropriate cells and expression of their potentialities. Available evidence is, overwhelmingly in favour of selective theories.

What are antibodies ?

Antibodies are proteins belonging to a class called 'gamma globulins' or immunoglobulins. Most of them circulate in the blood as a fraction of the plasma proteins. But one type, called

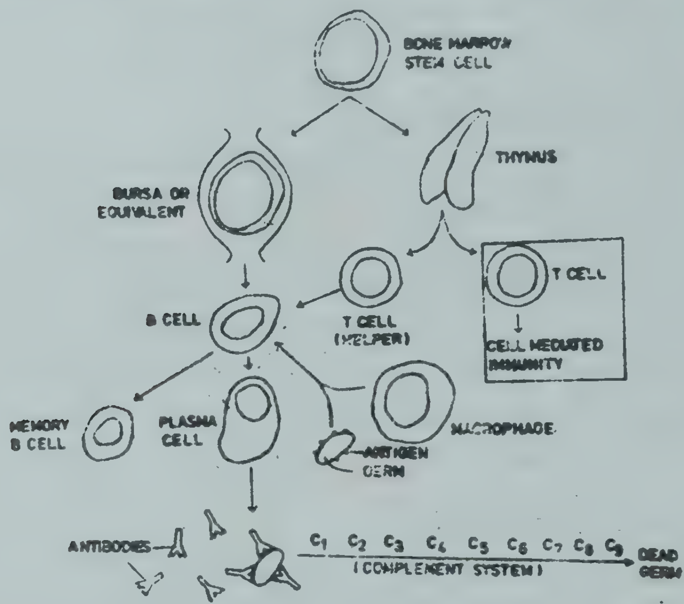

Fig. 31 Humoral immunity. When exposed to an antigen, it requires the cooperation of the macrophages and helper T cells to transform appropriate B cells into antibody forming plasma cells. An additional product is a memory B cell, which would result in a prompt and intense antibody response to any subsequent exposure to the same antigen. Details in text.

IgA, is present in secretions like those of the mouth, intestines, nose and eyes. IgA molecules keep these surfaces coated so that germs cannot enter our body through delicate surfaces.

How do antibodies work ?

If the antigen is a toxic substance, the antibody binds it. The complex is harmless and can circulate without doing us any harm. If the antigen is part of a germ, binding of the antibody to the antigenic site is not the end. The binding sets into motion a train of events which results in death of the germ. The events involve another set of substances circulating in the blood, collectively called the complement because these substances complete the job of the antibody. After the germ-antibody complex has been joined

by all components of complement, a hole is stabbed into the cell wall of the germ, thereby killing it.

2. Cellular immunity

Humoral immunity is manifested in the form of circulating antibodies, and is, therefore, most effective against germs and poisons which circulate in the blood. However, there are many germs which take shelter within the cells of the body and rob them or harm them right under their nose. For such organisms, there is another variant of the immune response in the body. Here also, the macrophage processes the antigen and brings it in contact with the T lymphocytes (Fig. 32). The result of this contact is to

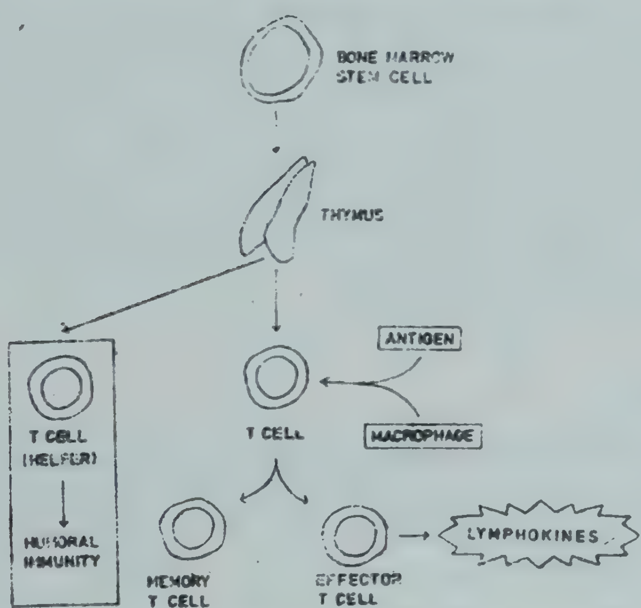

Fig. 32 Cellular immunity. The antigen is 'processed' by the macrophages, and then presented to the T cells. Details in text.

convert tranquil T cells into 'killer' T cells, technically called sensitized T cells. Sensitized cells not only deal with the organism directly, but also indirectly by stimulating the proliferation of similarly sensitized T cells all over the body. Besides this penchant for multiplying their own tribe, sensitized T cells neither forgive nor forget the enemy. Because of their good memory, they swing into action promptly whenever the same organism invades the body again.

The direct effect of sensitized T lymphocytes on the invasion is two-fold.

(i) They hunt for the cells which have been invaded by the germs and kill them (the cells). The ideal way to go about things, perhaps, would be to kill only the germs, leaving the cells intact and healthy. But that does not seem to-be possible. The best under the circumstances, therefore, is to resort to a radical measure : kill the cell to get rid of the germs within it; if the cell dies, the germs also die. It is a measure akin to amputating a limb with an incurable cancer.

(ii) They produce a family of soluble chemical substances, collectively called lymphokines. Without going into the individual effects of each recognized lymphokine, one might say that their overall effect is to attract the different white cells of the blood which help in fighting the infection, to prevent proliferation of germs, to stimulate the production of more similarly sensitized lymphocytes, and to increase the resistance of host cells to some types of germs. In short, by killing the cells harbouring the germs, and by producing lymphokines, sensitized T lymphocytes make life miserable for the invading organism.

Immunization

A major limitation of the immune mechanisms of the body described above is that they come into play only after the noxious agent has entered the body. The response to the first attack is relatively slow and weak, and therefore, the agent often does some harm before being vanquished. If we can artifically mimic the first attack in such a way that it evokes the immune response without producing symptoms of the disease. the first real attack will be treated by the body as a second attack. This is what we generally do when we immunize an individual (Fig. 33) In order to produce the first disease-free attack, the germ is killed or suitably modified and then injected in a measured quantity. The major problem of preparing a vaccine, therefore, is to find the right procedure for the specific germ in question. The procedure has to be such that the germ loses its capacity to induce disease while retaining its capacity to evoke an immune response. Vaccination is the single most cost-effective tool of preventive medicine which brings measurable results within a relatively short

period of time. Eradication of small pox from the world can be reasonably attributed to vaccination; as a result, routine use of small pox vaccine has already been stopped in some parts of the world, and the rest of the countries are likely to do so in the near future. BCG, DTP (Diphtheria, tetanus and pertussis) and polio vaccines have all been shown to be significantly

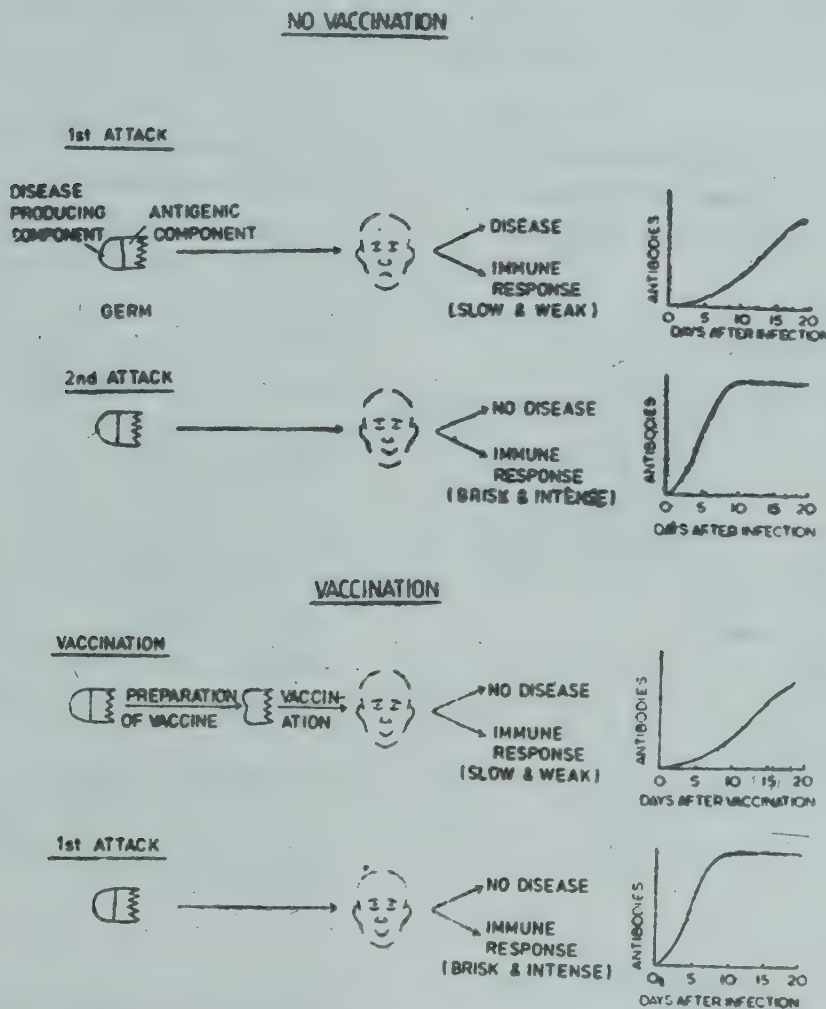

Fig. 33 Principles of immunization. The antibody response to the first attack by a germ is slow and weak, and hence disease symptoms appear. But the second attack is promptly aborted by the brisk and intense antibody response. Vaccination makes use of these facts. The first attack is simulated by vaccination, which, however, does not produce the disease because only the antigenic component of the germ has been injected. The first real attack by the germ is now treated by the body as a second attack in an un-vaccinated individual, resulting in protection from disease.

effective vaccines in well controlled scientific trials, and the dramatic decline in these diseases in developed countries is partly attributable to the widespread acceptance of these vaccines.

There are innumerable schedules of vaccination, and each of them has some merit. The chief merit of the schedule given below is that it requires only 4 visits to a clinic during the first year of life after discharge of the newborn baby. Minimizing the number of visits required is obviously of great importance, particularly in circumstances prevailing in developing countries

Before birth

16th—20th week of pregnancy	Tetanus toxoid—1st dose
20th—24th week of pregnancy	Tetanus toxoid—2nd dose
36th—38th week of pregnancy	Tetanus toxoid—3rd dose

After Birth

At birth (within one week)		BCG
3 months	1st visit	Small pox, DTP and Polio
	2nd visit (after 4—6 weeks)	DTP and Polio
	3rd visit (after 4—6 weeks)	DTP and Polio
9—12 months	4th visit	Measles (one dose)
18—24 months		DTP and Polio
3 years		Typhoid and cholera (two doses, 1 month apart)
5—6 years (school entry)		DT (Pertussis vaccine is discontinued) Tuberculin test. If the test is negative, give BCG
10 years (leaving primary school)		DT
Throughout life		Typhoid and cholera (every year) Tetanus toxoid (every 3—5 years)

Allergy

Allergy is an instance where too much of a good thing proves bad. Sometimes the body treats ordinary harmless substances as

harmful and reacts to them by a volatile and exaggerated immunological response. The result is an allergic reaction. An allergic reaction can take many forms. Respiratory distress (as in asthma), running of the nose, or a skin rash are common manifestations. Immediate death, as happens in a few cases after a pencillin injection, is not so common. An allergic response may occur not only to drugs, but also to ordinary foods like banana or tomato, to pollen grains, to cosmetics, etc. The substance, the introduction of which is followed by the allergic reaction, is called the *allergen*. Besides treatment of an isolated attack of allergy, it is also important that the allergen be avoided in future. Difficulties arise mainly on two scores :

(i) the allergen may not be known, and
(ii) it may not be always possible to avoid an allergen, e.g. pollen grains.

The first difficulty may be resolved sometimes by eliminating all the suspected allergens from the life of the victim and then introducing them cautiously one by one. It goes without saying that the substance identified as the allergen should be avoided ever after. This method is particularly applicable if the allergen happens to be a food or a cosmetic.

The second difficulty can be overcome to some extent by desensitization, which essentially involves regularly repeated injections of the allergen, starting with a very low dose and increasing it gradually. Desensitization is a time consuming and laborious process. Recently a nasal filter has been invented, which may prove a boon to those allergic to inhaled particles like dust and pollen.

CHAPTER 10

ENDOCRINES : THE POSTAL SYSTEM OF COMMUNICATION AND COORDINATION

The human body is comparable to a civilized society. Just as individual members of the society specialize in different tasks, different parts of the body also perform a specific function. However, as in the society, all parts are interdependent, and work towards a common goal — the welfare of the whole. It is easy to visualise the contribution of the farmer, the weaver and the scavenger to the existence of the society, just as the contribution of the heart, lungs or kidneys to our survival can be easily grasped. But one should not forget in the process the organiser, be it the village headman or the massive machinery of the government. The organiser may himself do nothing, but he keeps track of what everybody is doing and sees to it that everybody's activities are directed towards general good. In other words, the organiser is in to and fro communication with the parts. On the basis of the intelligence gained from them, it guides them into coordinated activity. In man and other complex living organisms, the function of the organizer is performed by two systems—a set of chemical messengers called hormones, and the nervous system. Hormones are slow in their action, and may be compared with the postal system. The much faster nervous system is comparable to the telegraphic system, and will be dealt with in the subsequent chapters.

Hormones

Hormones are chemical substances manufactured by organs called endocrine glands (*endon*, within; *krinein*, to separate) or ductless glands. The nomenclature signifies the fact that these glands pour their produce (or what they have 'separated') directly

into the blood stream, without its having to pass through a duct. In contrast, glands like salivary glands guide their secretions to their destination by means of tubes, called ducts. That is why such glands are sometimes called exocrine glands (*exo*, outside). Though hormones travel all over the body in the blood stream, many of them act only in selected organs (called target organs). The specific affinity of a hormone for a target organ is explained by the premise that receptors for the hormone are restricted to the target organs. The target organ of a hormone may be close to its site of production, or may be far away from it.

Small quantities of hormones bring about major shifts in metabolism resulting in pronounced effects on structure and function. The timing and quantity of a hormone released is finely controlled. The endocrine gland usually has mechanisms to monitor the requirements of the body for the hormone it produces. In other words, there is a link from the target organ to the endocrine gland through some end result of the hormone's action, often a metabolic product. The endocrine gland is affected by this metabolite in such a way that when there is a deficit of the metabolite produced by the effect of the hormone, the endocrine gland becomes more active, thereby correcting the metabolic picture. In other words, the target communicates with the endocrine gland through a code. The endocrine gland decodes the message, at times it integrates messages from different sources, and translates its 'decision' in the form of the rate of release of its hormone. The hormone now carries the message to the target organ where it is decoded in terms of its metabolic effects. The metabolic effects are such as to result in a better co-ordination of bodily activities.

Hormones are sometimes likely to be confused with enzymes and vitamins. *Enzymes* catalyse only a single specific chemical reaction, while hormones usually alter the rate of chains of enzymic reactions. Secondly enzymes are not the primary components of a communication system for coordinated activity, though they are the tools through which hormones act. Chemically, all enzymes are proteins, while hormones are either polypeptides or steroids. *Vitamins* affect chains of enzymic reactions in a manner similar to hormones, but unlike hormones, they are not manufactured in the body. Vitamins have to be supplied readymade to the body, usually in the diet.

The way hormones have been detected one by one makes interesting reading. The first hormone was discovered at the beginning of twentieth century. At the University College, London, William Maddock Bayliss and Ernest Henry Starling were trying to study the control of secretion of pancreatic juice. They separated a segment of the duodenum from the rest of the intestine and severed its nerve supply, so that the intestinal segment was connected to the rest of the body only through its blood supply. They found that if acid was placed in the segment of the duodenum, pancreatic juice was poured into it. Since the link between this segment and the rest of the body was only through the blood stream, it was inferred that perhaps acid in the duodenum results in some secretion into the blood stream which reaches the pancreas and provokes it to discharge its juice. The really critical experiment was, however, performed on the afternoon of January 16, 1902. A piece of the duodenum was ground up and its acid extract was injected into the blood stream.

This also resulted in pancreatic secretion, while injection of acid alone did not produce the pancreatic secretion. This conclusively demonstrated that the duodenum can supply a substance which upon getting into the blood stream stimulates pancreatic secretion. Bayliss and Starling called the afternoon of the experiment 'a great afternoon' which it truly was. They tried to further refine the active principle from the duodenum; and christened it secretin (*secrenere*, to separate). They also coined the term hormone (*hormaein*, to excite)* for this general class of substances, which shows that they had an intuition that many more substances of a similar nature would be discovered. Their hope has been amply borne out by the large family of hormones known today.

All hormones have not been discovered in this fashion, however. The clue to many of them was obtained from patients who had an excess or deficiency of one of the hormones. Correction of the symptoms by removal of a gland, or injection of its extract suggested a hormonal basis for the symptoms. The nature of the symptoms gave a clue to the function of the hormone in the normal individual. The experiments of nature on man were then

*All hormones do not excite the way secretin excites the pancreas ; in fact, many of them inhibit. But by common usage, the term hormone has come to be applied to all such substances.

deliberately repeated on animals. Appearance of similar symptoms in the animals lent further support to the conclusions. It is largely by such procedures that the foundations of endocrinology were laid.

Mechanism of action of hormones

Each hormone acts in its own way, and their ways are not completely understood. But if the known mechanisms are generalized, one might say that hormones affect cellular activity at one of the following steps (Fig. 34).

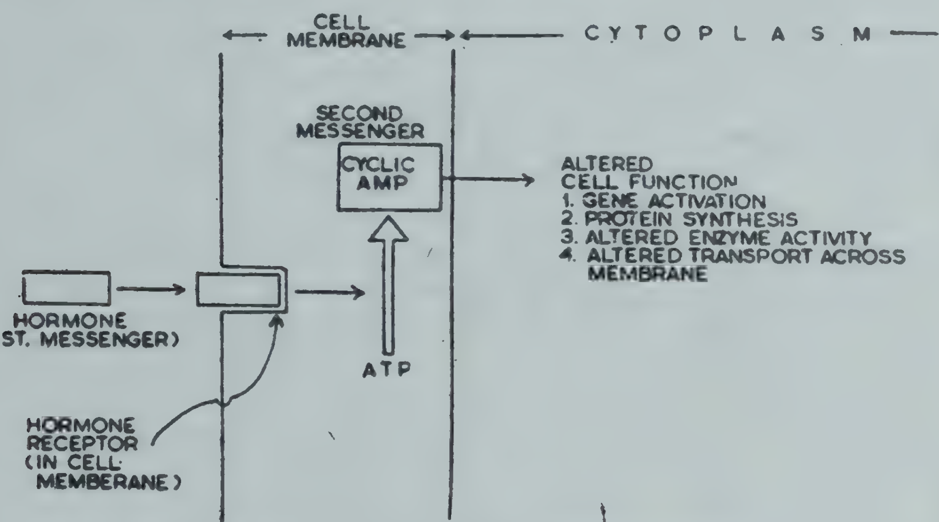

Fig. 34 Mechanism of action of hormones.

(i) Transcription of genetic information (DNA) in the nucleus to messenger RNA.
(ii) Synthesis of proteins
(iii) Activity of enzymes
(iv) Transport of substances into and out of the cell across the cell membrane.

One might further generalise that steroid hormones affect transcription and protein synthesis, while polypeptide hormones affect enzyme activity. An enzyme stimulated by a considerable number of hormones is the membrane-bound adenyl cyclase. Adenyl cyclase breaks down ATP to cyclic AMP. Cyclic AMP travels to the interior of the cell and affects a chain of enzymic reactions. Since the hormone carries a message upto the surface of the cell, and then cyclic AMP carries it further into the cell,

cyclic AMP is sometimes referred to as the second messenger (Fig. 34). There is evidence for the cyclic AMP mechanism being used by at least the following hormones : glucagon, epinephrine, TSH, ACTH, MSH, ADH, glucocortiocoids, thyroid hormone, luteinizing hormone, insulin, parathyroid hormone and estrogens. All these and other hormones will come up one by one in the subsequent pages.

Endocrine glands of the body

The time-honoured, better-understood endocrine glands of the body are the following (Fig. 35).

1. Thyroid

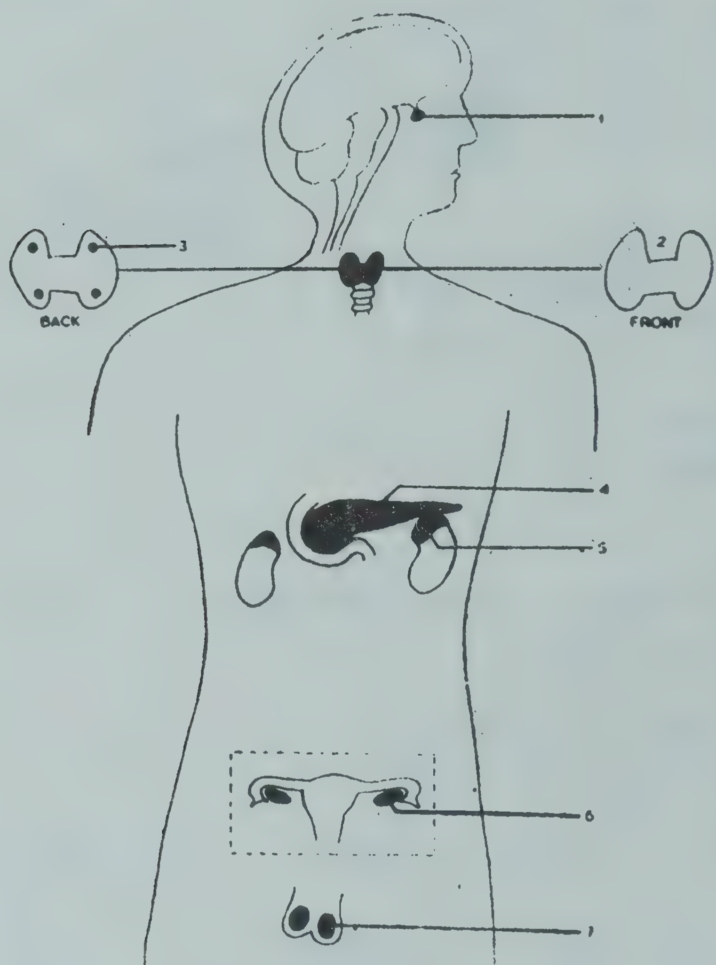

Fig. 35 The endocrine glands of the body.
1, pituitary; 2, thyroid; 3, parathyroid; 4, pancreas; 5, adrenals; 6, ovaries (in famales); 7, testes (in males).

2. Pancreas
3. Adrenals
4. Gonads
5. Parathyroids
6. Pituitary

1. Thyroid

Thyroid gland is situated in the neck in front of the wind pipe. It manufactures two closely related hormones : triiodothyronine (T_3) and tetraiodothyronine (T_4), also called thyroxine. As indicated by their names, both these hormones contain iodine. Their actions on the body are qualitatively the same; it is only that T_3 acts much faster but for a shorter period of time than T_4.

Thyroid hormones fan the metabolic processes of the body. Almost all chemical reactions are speeded up, and the heat production by the body increases. These effects are manifested by an increase in the body temperature and heart rate, and a general increase in the tempo of physical and mental activity.

With this background, it is not difficult to understand the effect of diminished thyroid activity (hypothyroidism : *hypo*, under) on the body. The effect is more marked in childhood, since rapid growth and development require optimal thyroid activity. Since the brain is the organ that develops the fastest in early childhood, it is seriously affected by deficient thyroid function. Hypothyroidism in childhood gives rise to a condition called *cretinism.* A child born with this malady may be heavier than the average normal newborn. He feeds less, sleeps more, and has a large tongue (Plate 8). The large tongue may make his breathing noisy, his voice hoarse, and may give him choking spells. He appears uninteresting and uninterested, and is often constipated. His extremities may feel cold to touch. He is slow to learn, as shown by the age at which he begins to sit or stand. As he grows up, his handicap becomes more apparent, and he develops into a physically and mentally retarded individual. However, if the disease is detected within the first few months of life, the child can be made to develop properly by daily administration of adequate doses of the thyroid hormone. If the treatment is started within the first three months, about half the children attain intelligence in the normal range. If the disease is detected late, the physical development can still be restored to essentially normal level by

the thyroid hormone, but there is no way to make up for the damage already inflicted on the brain. In view of the great importance of mental function, it need hardly be emphasized that the attention of a doctor should be sought promptly if an infant is found to be cool, callous or constipated.

If hypothyroidism sets in in an adult, the effects are not as serious as in a child. The individual becomes physically and mentally sluggish, his voice becomes hoarse, he gains weight and gets constipated. He finds it difficult to tolerate cold, even in summers he may insist on sleeping indoors with a blanket on. On examination, his resting heart rate and body temperature are found to be low. This combination of features is called myxoedema (Plate 9). All symptoms of hypothyroidism in the adult can be reversed by thyroid hormone. However, once the patient feels fit, there is a temptation to stop the medication. It should be realised that in this case, the thyroid hormone is only trying to make up for the deficiency of a substance that is normally produced everyday in the body. Therefore its requirement is lifelong. Withdrawal of the thyroid hormone results in return of all the symptoms. In view of the above discussion, it will not be surprising if some of the readers who feel sluggish off and on (and everybody does, sometime or the other) get tempted to take some thyroid pills for extra zest and vigour. However, this step is not to be taken lightly and needs careful laboratory tests and consideration by a doctor. Too much of a good thing can also be bad, as will be evident from the symptoms of the disease in which the thyroid gland becomes overactive (*hyperthyroidism* ; *hyper*, above). The unfortunate victim of this condition feels very hot; he can brave the winters without woollens, but feels miserable in summers. He may have diarrhoea, tremulous hands, and loss of weight in spite of a voracious appetite. On examination, his resting heart rate and body temperature are raised. For ill understood reasons, some of these patients have markedly protruding eyes (Plate 12). Hyperthyroidism may be treated by some drugs, or by surgical removal of the thyroid gland.

Goitre

Goitre is an enlargement of the thyroid gland. It manifests itself as a swelling in the neck. A goitre may be associated with

increased, normal or decreased activity of the thyroid gland. The phenomenon of an enlarged thyroid showing more activity than a normal sized one is quite understandable. The association of a goitre with normal or decreased function may be explained as follows. If the thyroid gland is primarily less active than normal, the body tries to attain normalcy by enlarging the thyroid. The enlarged thyroid may be able to perform normal function, or may still remain less active in spite of becoming large. This explanation will become more clear after the study of regulation of thyroid activity (see below). In India, a goitre of this variety is highly prevalent in hilly areas of the sub-Himalayan belt (Plate 10). In these regions the soil is deficient in iodine. Therefore, the plants grown there are also iodine-poor. Since iodine is an essential component of thyroid hormones, in a situation of iodine scarcity a normal sized thyroid gland is unable to trap enough iodine to manufacture the normal quantity of hormones. The body tries to correct the defect by stimulating the thyroid to grow bigger and often this enlarged thyroid is able to manufacture the normal quantity of hormone in spite of iodine deficiency. That is why many otherwise normal people can be seen going round in these regions with large swellings in their necks. For cosmetic reasons, and to avoid the possibility of a cretin being born to them, it is desirable that the population should be normal in every respect. This can be achieved by supplying some iodine in the diet. The surest way to make iodine universally available in the area is to mix 0·01% of the iodine containing salt, potassium iodide, with table salt, and to ban the sale of plain table salt in the region.

Regulation of thyroid secretion

In view of the undesirable effects of decreased or increased thyroid activity, one might wonder how the activity stays at the normal level in most of us. It is all the more remarkable because normal thyroid activity fluctuates according to requirements, being more during exercise than at rest, more in winters than in summers. The regulation is by means of another hormone secreted by the anterior (front) part of the pituitary gland. Since this hormone stimulates the thyroid gland to manufacture and release more thyroid hormones, it is called *thyrotropin* or *thyroid stimulating hormone* (T S H). The amount of TSH secreted depends on the circulating level of thyroid hormones—less the level, more the

TSH secretion. More TSH secretion means release of more thyroid hormones, correction of the deficit, and also simultaneous withdrawal of the stimulus which prompted the TSH surge in the first place (Fig. 36). Thus the system is self-adjusting like the ther-

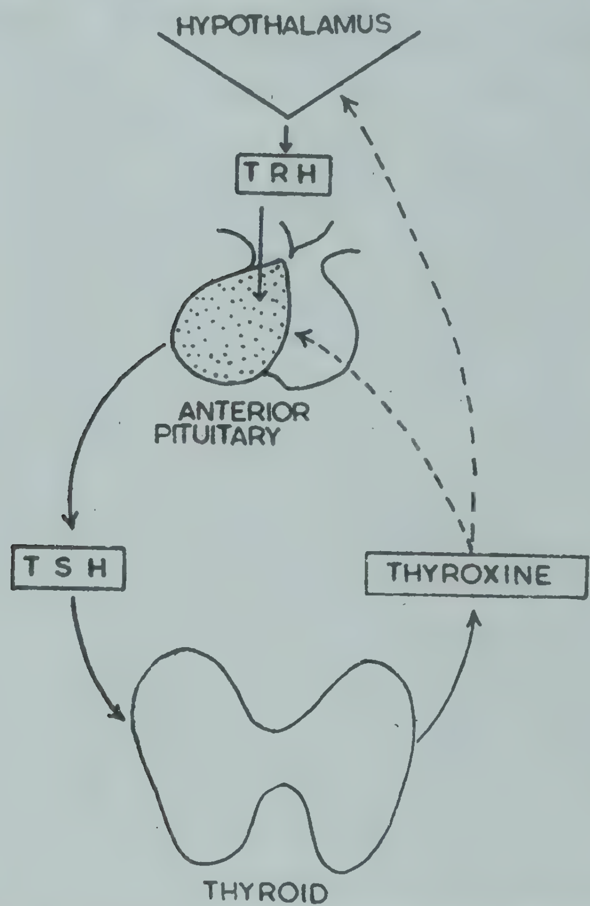

Fig. 36 Regulation of thyroid activity. TSH Release Hormone (TRH) is manufactured by the hypothalamus. It stimulates the release of Thyroid Stimulating Hormone (TSH) from the anterior pituitary. TSH stimulates the release of thyroid hormones (thyroxine). Thyroxine, in turn, *inhibits* the release of TRH and TSH, thus keeping its own levels in check.

mostat in an oven or automatic electric iron. So long as the temperature is below that required, the instrument remains on. As soon as the desired temperature exceeds, the thermostat acts by switching the instrument off. When the temperature falls just

a little below that desired, the thermostat makes sure that the heating element is again switched on. In the present instance, the temperature is comparable to the thyroid hormone level, the instrument is comparable to the thyroid gland, and the thermostat is comparable to TSH. This type of mechanism is spoken

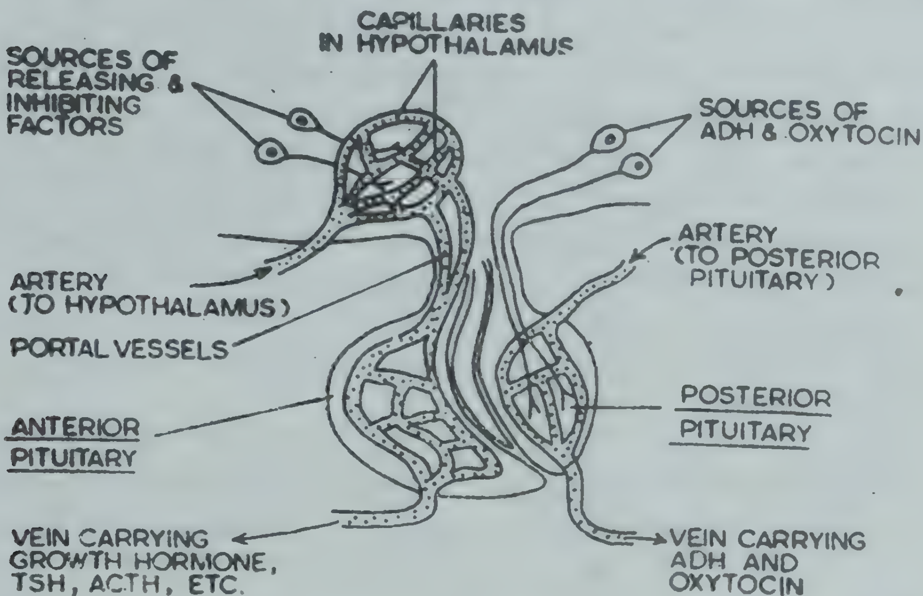

Fig. 37 The intimate structural and functional relationship between the hypothalamus (a part of the brain), and pituitary (an endocrine gland).

The anterior pituitary is connected to the hypothalamus by means of blood vessels. Neurons which synthesise releasing and inhibiting factors for anterior pituitary hormones are located in the hypothalamus. These factors are released in the hypothalamus in the vicinity of capillaries. These capillaries transport the factors via the portal vessels to the capillaries of the anterior pituitary. In the anterior pituitary, the factors migrate out of the capillaries into the intercellular spaces and exert their influence on the synthesis and release of anterior pituitary hormones.

The posterior pituitary is connected to the hypothalamus more directly. The hormones of the posterior pituitary are manufactured by nerve cells located in the hypothalamus, but the hormones are stored in the posterior pituitary. These hormones get transported from the posterior pituitary to their target organs in the blood stream as in the case of any other endocrine gland.

of as regulation by negative feedback. The next question then is, how does thyroid secretion vary with the requirements instead of being fixed at a constant level. This is because TSH is also

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affected by another hormone called thyrotropin release hormone (TRH) released by the hypothalamus—a part of the brain. Information about the various conditions requiring change in thyroid hormone level reaches the brain. Within the brain it gets funneled to the hypothalamus. The hypothalamus translates it in terms of appropriate changes in secretion of TRH. There is a special arrangement for conveying TRH to the anterior pituitary. TRH is drained into the vein leaving the hypothalamus. Soon after leaving the hypothalamus, this vein breaks into a set of capillaries in the anterior pituitary through which TRH can diffuse out into the pituitary. On coming into contact with the cells of the anterior pituitary, TRH provokes them to release TSH into the blood stream. TSH, in turn, stimulates the thyroid to form and release its hormones. The scheme of regulation of thyroid activity, which is similar to that for regulation of many other hormones as well, is illustrated in Fig. 37.

Although hormones are regulators of metabolism, it is seen that they themselves are also regulated. The situation is similar to that in the human society where administrators are themselves 'administered' by those higher-up in the hierarchy. The hierarchy in the case of thyroid gland is sometimes spoken of as the hypothalamo-pituitary-thyroid axis.

2. Pancreas

The pancreas has already been introduced as a part of the digestive system. The same organ also manufactures two important hormones. The endocrine department of the pancreas is scattered throughout its substance in the form of tiny islands. The islands have been named 'Islets of Langerhans' to honour the memory of Langerhans who was the first to observe them under the microscope when he was just twenty-two. The islets have two major types of cells called A and B. The A cells secrete the hormone *glucagon*, while the B cells secrete the well-known hormone insulin (*insula*, island). In view of its importance, insulin shall be discussed first.

Insulin

The association between diabetes and impaired pancreatic function has been known for very long. But the discovery of the antidiabetic principle from pancreas eluded many able investiga-

tors. The credit for the discovery ultimately went to a young surgeon, Frederick Grant Banting, and a medical student, Charles Herbert Best. They named the substance insulin (*insula*, island) because it is manufactured in the islets (*islet*, island).

Insulin affects significantly the manner in which carbohydrates, proteins and fats are utilised in the body. In general, one might say that insulin promotes utilisation of glucose in all possible ways, and also stimulates the synthesis of proteins and fats. As a result of the effect of insulin, more glucose is broken down to provide energy. The utilization of glucose for synthesis of glycogen and fats is also enhanced by insulin. The manufacture of glucose from protein sources is, on the other hand, depressed by insulin. The net result of the action of insulin, therefore, is to reduce the quantity of glucose in the body, and consequently the concentration of glucose in the blood also falls. Since insulin encourages the utilization of glucose for producing energy, proteins and fats are spared from being used as fuel. Besides this indirect effect, insulin also has a direct effect of increasing the synthesis of proteins and fats, thereby promoting growth and gain in weight.

The rate of release of insulin into the blood fluctuates many times in a day depending on the requirements of the body at a particular instant. The pancreas seems to assess the insulin requirements of the body from the blood glucose level. Insulin is poured into the blood when the level of glucose rises, and insulin release declines when the level of glucose has fallen to a critical level. This ensures the maintenance of blood glucose level within a narrow range. The mechanism is called into action several times a day, i.e. whenever we eat and whenever we exert ourselves, because while eating adds glucose to the blood, exercise uses up glucose.

Reduction in the quantity of effective insulin gives rise to diabetes mellitus (*diabetes*, siphon ; *mellitus*, of honey), commonly called simply diabetes. Deficiency of insulin reduces the quantity of glucose utilised, leading to its accumulation in the body. Hence the blood glucose level rises, and may rise so much as to exceed the reabsorptive capacity of the kidneys. In that case, glucose spills over in the urine causing the most commonly known symptom of diabetes, viz. sugary urine. Since the urine contains glucose, the

urine also has to have enough water to dissolve it. Therefore, a diabetic passes large quantities of urine, and often has to get up a number of times at night to pass urine. The body compensates for excessive urination by making the patient feel unduly thirsty. On one hand, the patient is unable to utilise enough glucose for getting energy, and on the other the utilization of proteins and fats cannot fully compensate for the defect. Therefore, the patient is effectively "starved in the midst of plenty" : he virtually bathes in a sweet solution without being able to use the sugar. That is why loss of weight and excessive appetite are other symptoms of diabetes. In short, a diabetic eats a lot, drinks a lot, passes plenty of sugary urine, and loses weight.

The treatment of a diabetic is based on the interplay of food, exercise and insulin. Food adds glucose to the blood, while exercise and insulin remove it. First, we alter the diet in a manner that it adds glucose to the blood rather slowly. This can be done by reducing the sugar content of food, taking carbohydrate in the form of starch as far as possible. Second, we facilitate utilisation of glucose by encouraging physical activity. For many elderly patients with mild diabetes, these two measures are all that is necessary by way of treatment. But some diabetics need additional assistance in the form of insulin. Here the doctor tries to mimic nature by supplying insulin in situations in which it is normally relessed in non-diabetics. However, man is not as perfect as nature. Insulin once injected cannot be switched off, the exact quantity to be supplied in relation to every different meal cannot be accurately predicted, and the number of injections given in a day has to be kept at a minimum.* In view of these limitations, a patient on insulin has to keep his daily diet and exercise constant. If he takes a heavy meal, his insulin will not be enough. Even more serious is the situation if he misses a meal but does not miss

*Insulin has to be given by injection. It cannot be given by mouth because, being a protein, it is digested to amino acids in the gastrointestinal tract. However, some diabetics can now be treated by oral pills. These pills act by either stimulating the patient's own B cells of the pancreas to release more insulin, or by increasing the utilisation of glucose. Both these groups of drugs require that the patient should have at least some B cell function left. Therefore, pills are usually suitable only for elderly diabetics. Young diabetics are generally devoid of any substantial insulin secretion of their own.

the insulin. In that case, the blood glucose level can fall to dangerously low levels. An unaccustomed exertion, associated with the usual dose of insulin but no extra food, can also lead to the same serious consequence by consuming extra glucose.

The above account gives only the most important principles of treatment. The actual treatment requires attention to many minor but important details which are beyond the scope of this book.

Glucagon

This is a hormone with many interesting functions, some of them supplementing those of insulin, and some independent ones. Many facts about glucagon have been learnt only recently, and a lot perhaps still remains to be learnt.

Glucagon increases the breakdown of glycogen to glucose and stimulates the formation of glucose from amino acids, thereby raising blood glucose level. It might be observed that these effects of glucagon are opposite to those of insulin. The cells within the islet seem to influence each other's activity. Insulin inhibits A cells from producing glucagon, while glucagon, paradoxically, stimulates B cell activity resulting in release of insulin. Glucagon is likely to have an important role in the economy of the body as a switch for insulin and as a counterbalancing force for the effects of insulin.

3. Adrenals

Adrenals (or suprarenals) are a pair of endocrine glands lying adjacent to the kidneys. Their outer part is called the cortex and the inner core is known as the medulla (Fig. 26). Though structurally the adrenal cortex and medulla are joined together, their functions are independent enough to be discussed separately.

Adrenal cortex

Adrenal cortex secretes three sets of hormones into the blood stream which affect three different aspects of body function.

(i) Mineralocorticoids

These hormones are important for maintaining an appropriate composition of minerals in body tissues. The most important hormone of this family is *aldosterone*. Aldosterone acts primarily

on the kidney to conserve salt (sodium) and water. On the other hand, it speeds up the loss of potassium in the urine. Through these actions, aldosterone affects not only water and salt balance, but also blood pressure and acid base balance. These are functions basic to homeostasis, and are more important than the functions performed by other hormones of adrenals. Thus, if an animal's adrenals are removed, it dies. But the animal can be kept alive in a protected environment, provided it is supplied a mineralocorticoid through injections.

The regulation of aldosterone secretion is complex and controversial. As may be expected, the sodium and potassium status of the body influence it appropriately with the clear goal of maintaining their quantities in the normal range. The other important regulatory influence is through the arterial blood pressure. This is also easy to understand. Retention of sodium in the body is accompanied by retention of water. Their retention increases the fluid volume, including the blood volume, of the body. More blood filling the blood vessels means higher blood pressure. For convenience, let us start with low blood pressure. This, in turn, increases the secretion of a hormone, called renin, from the kidneys. Renin interacts with a protein in the blood to form a substance called angiotensin. Angiotensin, besides raising the blood pressure directly by narrowing the blood vessels, also increases aldosterone secretion. Aldosterone promotes sodium retention, and secondarily water retention too, which together raise blood pressure, bringing it towards normal. This complex chain of renin angiotensin-aldosterone thus regulates water and salt balance, as well as blood pressure. Besides these mechanisms, an organ at the base of the brain, the pineal gland, has also been implicated in the regulation of aldosterone secretion.

(ii) Glucocorticoids

The most important member of the family of glucocorticoids is hydrocortisone, also known as cortisol. As their name implies, these hormones affect glucose metabolism. They increase glucose synthesis from amino acids, and decrease utilization of glucose, the net result being an increase in the blood glucose level. But this is only a very limited aspect of the function of glucocorticoids. They also mobilise cellular proteins and fats. Amino acids made available in the blood stream by mobilization of proteins are utili-

zed to synthesize more proteins in the liver and wherever else needed. The fatty acids derived from fats are utilized to get energy. All these biochemical effects put together constitute a useful aid to the body in periods of stress. The additional amino acids extracted from tissue proteins can build up liver reserves, be utilized for manufacturing antibodies, or be diverted to synthesis of glucose. Mobilization of more fatty acids places a rich source of energy at the disposal of the body. That the glucocorticoids are useful in periods of prolonged stress is suggested by the rise in their level during such periods, and the inability of an animal deprived of its adrenals to face a stressful situation.

The secretion of glucocorticoids is regulated by a mechanism similar to that for the regulation of thyroid hormones. The hypothalamus sends the hormone corticotropin-release hormone (CRH) to the anterior pituitary via the portal system. The anterior pituitary responds to CRH by releasing another hormone, corticotropin or adrenocroticotropic hormone (ACTH). ACTH acts on the adrenal cortex to release glucocorticoids. The glucocorticoids, in turn, feed back to the hypothalamus and pituitary, tending to suppress CRH and ACTH release. Any long standing physical or mental stress apparently gets siphoned to the hypothalamus. Stimulation of appropriate quarters in the hypothalamus is ultimately manifested as enhanced synthesis of glucocorticoids.

The link between stress and adrenal activity was discovered by Hans Selye before the hypothalamo-pituitary-adrenal axis had been worked out. Selye grouped the body's response to stress into three phases : (i) *alarm*, (ii) *adaptation* and release of glucocorticoids, and if the stress was beyond adaptation, (iii) *exhaustion*. However, Selye's concept of stress is broad and does not carry the popular connotation of being sporadic and always undesirable. In this broad sense, stress is a necessary accompaniment of life; no living being ever lets his adrenal cortex stay idle. As Selye has said, "A painful blow and a passionate kiss can be equally stressful".

(iii) Androgens and estrogens

The last category of adrenal cortical hormones are the sex hormones, androgens and estrogens. Normally their quantities produced are too little to be of significance in sexual development. But under some abnormal circumstances, the male hormones may

be produced in sufficient quantity to cause early sexual development in a boy or masculinization of a girl.

Adrenal medulla

The inner portion of the adrenal glands, the medulla, secrets the hormones adrenaline (epinephrine) and noradrenaline (norepinephrine). These hormones are released in a rapidly developing stress, and produce metabolic effects which are beneficial in such a situation. In an emergency, not only is adrenal medulla activated, a division of the nervous system is also activated. This division is called the sympathetic nervous system because it sympathises with us in an emergency. Sympathetic nervous system operates through the release of nearly the same chemicals which are released by the adrenal medulla, and its effects are also similar. Sometimes the whole functional unit is referred to as sympatho-adrenal system. Some more details about the sympathetic nervous system will be discussed in the next chapter. At this stage, it might be mentioned that the adrenal medullary hormones push the heart and respiratory systems, thereby maximising the capacity of the body for a bout of physical exertion. Relatively unimportant activities like digestion are suspended. Metabolically, fuels are mobilised for immediate utilization, while synthetic functions are held in abeyance.

Thus both parts of the adrenal gland have not only a structural, but also a functional bond. Both are concerned with survival under adverse circumstances. The cortex helps us in prolonged problems, while the medulla comes to our rescue in suddenly developing short lasting calamities.

4. Gonads

Gonads are the sex organs—testes (sing, testis) in the male, and *ovaries* in the female. One of the important functions of gonads is to produce hormones. In fact, the maturation of all other sexual functions, including the maturation of gonads, depends upon the production of adequate sex hormones.

The male hormones are called *androgens*, the most significant member of the group being *testosterone*. Androgens are responsible for the growth and function of male sex organs and the development of the masculine features like growth of hair on the face and upper lip, hoarseness of voice, broadening of shoulders,

Plate 8. Two different consequences of deficient thyroid activity. On the left is a typical cretin. He is eighteen years old, but his poor growth and mental handicap make him look much younger. On the right is a goitrous deaf-mute with defective posture and gait. (Courtesy: Dr C S Pandav, Department of Endocrinology, AIIMS, New Delhi).

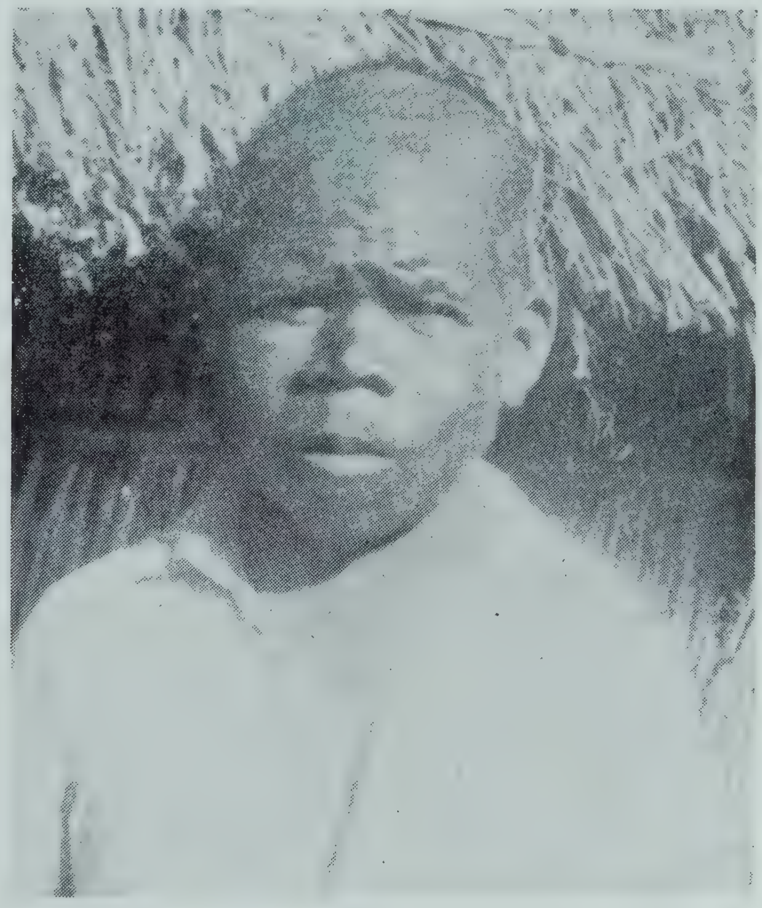
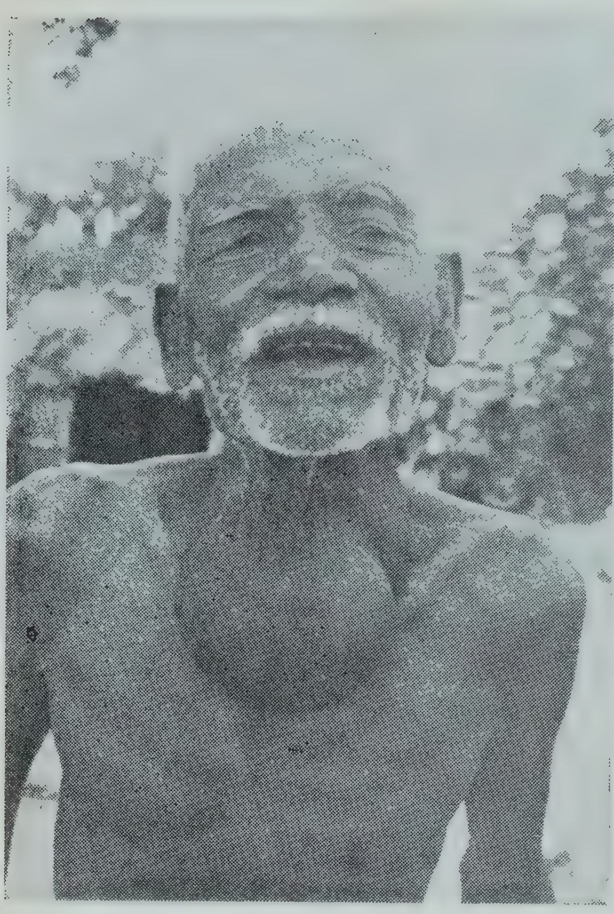


Plate 9. A thirty-five year old patient with myxoedema. His dull and coarse features are obvious. (Courtesy: Dr C S Pandav, Department of Endocrinology, AIIMS, New Delhi).



Plates 10 & 11. Two patients with endemic goitre. (Courtesy: Dr C S Pandav, Department of Endocrinology, AIIMS, New Delhi).

Plate 12. A female patient with enlarged thyroid (goitre) and protruding eyeballs (exophthalmos). (Courtesy: Dr C S Pandav, Department of Endocrinology, AIIMS, New Delhi).

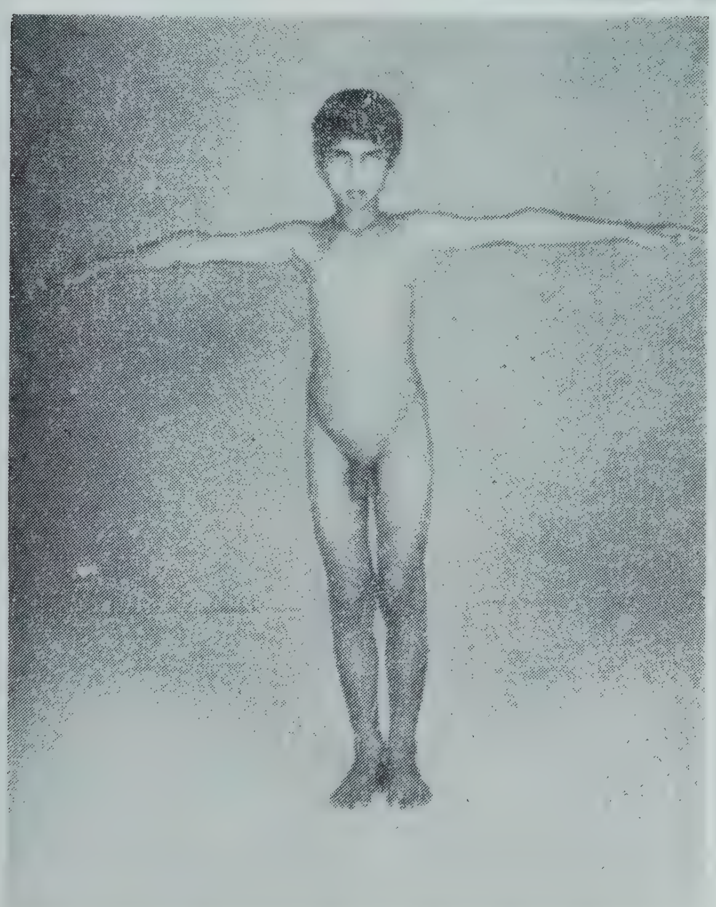


Plate 13. Adrenal glands sometimes start manufacturing male sex hormones far in excess of the normal quantity as in this boy, nine years old. He shows accelerated physical growth and precocious sexual development. (Courtesy: Dr C S Pandav, Department of Endocrinology, AIIMS, New Delhi).

Plate 14. Acromegaly.

A. Age 9 years, apparently normal.

B. Age 16 years, some coarsening of features seems to be present.

C. Age 33 years, well established acromegaly.

D. Age 52 years, gross disfigurement due to advanced acromegaly.

(Reprinted with permission from Clinical Pathological Confer *The American Journal of Medicine*, 1956, Vol. 20, p. 133. Courtesy: Editor, *The American Journal of Medicine*, and Technical Publis New York, U.S.A.).

and marked muscular development. The psychological effects of sex hormones are well-known to the farmer who castrates the bull to make it docile and disinterested in cows.

The female hormones are *estrogens* and *progesterone*. Estrogens are responsible for the growth and functions of sexual organs and development of secondary sexual characteristics of the female, e.g. enlargement of breasts, broadening of the pelvis, and deposition of fat at characteristic sites. On the other hand, progesterone equips a woman for pregnancy, and sustains the pregnancy during its early phase. The cyclic interplay of estrogens and progesterone results in the cyclic appearance of menses.

The remarkable effects of sex hormones, as seen in some animal experiments, are shown in Plate 13.

The regulation of sex hormone secretion is similar to that of thyroid hormones and glucocorticoids. The hypothalamus secretes gonadotropic release hormones, which act on the anterior pituitary to release gonadotropins. The gonadotropins, in turn, stimulate the gonads to manufacture and release sex hormones. The sex hormones feedback chiefly to the hypothalamus, to suppress the release hormones. It is thought that the hypothalamus is extremely sensitive to this inhibitory influence till puberty so that very small quantities of sex hormones formed in sex organs are enough to depress it. Puberty is ushered in by a relatively sudden decrease in the sensitivity of the hypothalamus to sex hormones. It is no longer suppressed by the existing low levels of sex hormones ; as a result, significant quantities of gonadotropic release hormones escape from the hypothalamus. This starts a chain reaction leading to a new equilibrium at a much higher level of sex hormones and its consequences.

Sex hormones will again figure in the discussion of reproductive function (Chapters 22 and 23).

5. Parathyroids

Parathyroid glands are situated behind the thyroid and hidden by it. There is a pair of them on either side, so that there are four of them in all. They are an important component of the system that looks after the fate of calcium in the body. Since calcium is an important constituent of bones and teeth, parathyroids particularly affect the integrity of bones and teeth.

The most important effect of parathyroids is on the bones. Parathyroid hormone (PTH) promotes the extraction of calcium from the bones. The calcium so extracted is released into the blood stream, raising its concentration in the blood. The other major effect of parathyroid hormone is on phosphate excretion in the kidneys. Phosphate is a companion of calcium in teeth and bones. PTH reduces reabsorption of phosphate from the renal tubules, thereby increasing its excretion in urine, and consequently decreasing its concentration in the blood.

The other participants in calcium homeostasis are :—

(i) Vitamin D, which primarily increases the absorption of calcium from the gastrointestinal tract, and

(ii) Calcitonin, a hormone produced by the thyroid gland, which primarily decreases the breakdown of bony subsance. In other words, the effect of calcitonin is essentially opposite that of PTH.

The interplay of PTH, vitamin D and calcitonin is responsible for maintaining a rather constant blood calcium level, and also bones and teeth in a healthy state. They do so by exerting a regulatory influence on the entry and exit of calcium, and by affecting its stay in the bone. The degree and nature of control exerted at all these points depends on the intake and demand of calcium in the body.

6. Pituitary

We have seen in the discussion of many of the glands above that their activity is regulated by the anterior part of the pituitary gland. That has already established its importance. In addition, pituitary also produces some hormones which have direct effects of their own on vital body functions.

Like the adrenals, pituitary is also made up of two independent parts — the anterior (front) part and the posterior (back) part.

Anterior Pituitary

The hypothalamus and anterior pituitary may be considered one functional unit. The relationship, as already discussed, is vascular (Fig. 37). The hypothalamo-pituitary portal vessels bring release hormones from the hypothalamus, which in turn release specific hormones from the anterior pituitary into the blood stream. Now we know that the hypothalamic control can work both

ways. Not only does it produce release hormones, it also produces inhibitory factors for some of the pituitary hormones. Now the various hormones of the anterior pituitary may be discussed.

(i) Growth hormone

As the name indicates, this hormone promotes growth. At cellular level, growth hormone increases both the transport of amino acids into cells, and their synthesis into proteins. There is a spurt of growth hormone secretion during certain phases of sleep—so there is something to the adage that children grow up during sleep. Contrary to expectation, the circulating growth hormone concentration in adults is the same as in growing children. Probably its function in adults is to boost up repair processes. Growth hormone secretion is regulated by a release as well as an inhibitory hormone derived from the hypothalamus.

Abnormalities can arise from deficient or excessive secretion of growth hormone.

(a) Deficient secretion

As would be expected, deficient secretion gives rise to stunted

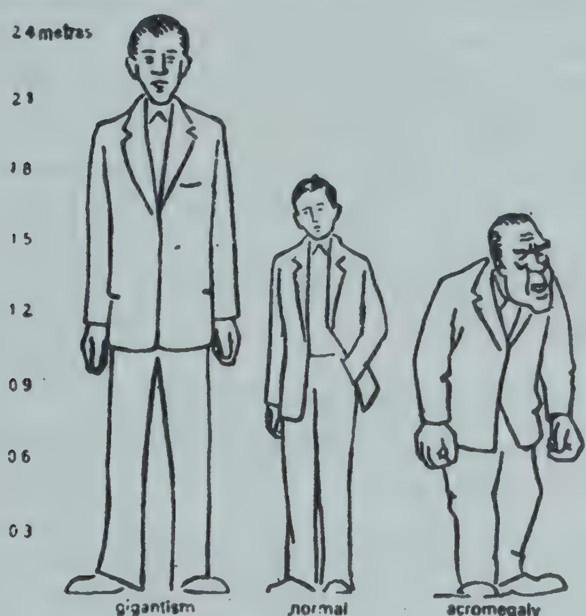


Fig. 38 The effects of excess growth hormone : gigantism and acromegaly.
(Reprinted, with permission, from Lewis JG. The Endocrine System, 2nd edition, 1984. Fig. 3.8, p. 44, Courtesy: Churchill Livingstone, Edinburgh, U. K.)

growth, but the body is well proportioned. The result is a dwarf. Growth hormone deficiency can be corrected only by the hormone obtained from human pituitaries. Fortunately, even cadaver pituitaries yield effective growth hormone. But, as would be expected, the supply of human growth hormone is extremely limited. Laboratory synthesis of human growth hormone is unlikely in the near future in view of the relatively large size of its molecule.

Growth is stimulated not only by growth hormone, but also by male sex hormones (androgens). But their use is handicapped by two additional effects, both undesirable in the present context. First, they hasten the termination of bone growth. That is why, if androgens are given, there is only a transient spurt of growth which is checked by arrest of bone growth. If bones cannot grow, height cannot increase any further. Second, androgens also have masculinizing effects which are particularly undesirable in girls.

(b) Excessive secretion

If excessive growth hormone secretion starts in childhood, the obvious result is a very tall individual, often called a 'giant' (Plate 14). However, if excessive secretion starts after linear growth has stopped, the ends of bones start protruding. There is an enlargement of jaws, hands, and feet, the back gets bent, and the individual eventually presents a gorilla-like appearance. This condition is known as 'acromegaly' (*akros*, extremity; *megas*, great) (Fig. 38).

(ii) Thyroid stimulating hormone (TSH)

It stimulates the thyroid gland, and has already been discussed.

(iii) Adrenocorticotropic hormone (ACTH)

It stimulates the adrenal cortex to secrete glucocorticoids, and has also been discussed earlier.

(iv) Melanocyte stimulating hormone (MSH)

It stimulates production of melanin (the skin pigment), and thereby makes the skin darker. In some animals like fish and frogs, it disperses melanin granules within cells, thereby enabling the animals to change their colour. Change of colour helps in matching the colour of the skin with that of the surroundings, and is a protective mechanism.

(v) Gonadotropins

(a) Follicle stimulating Hormone (FSH)

It stimulates the ripening of the egg in the ovary. It has a cyclical rise and fall, being more important during early ripening of the egg. In men, it stimulates formation of sperm in the testes.

(b) Luteinizing Hormone (LH) or Interstitial Cell stimulating Hormone (ICSH)

This hormone is also involved in ripening of the egg, and is more important during shedding and after shedding of the egg. In men, it stimulates the testes to produce the male sex hormone, testosterone.

(c) Prolactin or Luteotropic hormone (LTH)

These names refer to two of the many actions this hormone has. But all these actions are not seen in the same species. In women, it stimulates synthesis of breast milk. However, this effect is seen only if the breast has already been under the influence of estrogen, progesterone, corticosteroids and insulin. Such a situation is likely to be present particularly during and after pregnancy. The effect of the hormone on milk synthesis is the basis of the name, prolactin.

The second name refers to the effect the hormone has on the ovary after the shedding of the egg. The function is geared to preparation for pregnancy, and is seen in the female rat. The hormone also has growth hormone-like effects in some species.

Posterior pituitary

While the anterior pituitary is connected to the hypothalamus only by a vascular tree, the posterior pituitary may be considered an extension of the hypothalamus. In fact, the hormones released from the posterior pituitary are manufactured in a part of the hypothalamus, and travel along nerve tracts to the posterior pituitary from where they are released at appropriate moments. After going through the long list of hormones of the anterior pituitary, it may be a relief to know that the posterior pituitary releases only two hormones.

(i) Antidiuretic Hormone (ADH)

As the name indicates, this hormone reduces the volume of

urine formed. Its secretion is affected by blood volume, which in turn, reflects the water content of the body. This mechanism facilitates the maintenance of constant water content in the body. The mechanism has already been discussed in detail earlier (Chapter 8).

(*ii*) *Oxytocin*

This hormone has two main effects at important points in a woman's life.

(a) It makes the uterus contract forcefully during delivery, thus forcing the baby outwards. If a woman makes unduly slow progress at delivery, sometimes doctors give this hormone by injection to help the natural process.

(b) It expels milk from the breasts. As we have seen earlier, estrogens help the development of the breasts; prolactin and some other hormones stimulate the synthesis of milk in the breasts; but the final squeezing of the milk out of the breasts is brought about by oxytocin. The release of oxytocin from the posterior pituitary at the appropriate moment is triggered by the presence of the baby and suckling. That is why man, in his own interest, allows the calf to suckle for a few minutes to release the cow's oxytocin. Once oxytocin has been released, copious flow of milk ensues. The calf is then usually withdrawn, but oxytocin once released cannot be withdrawn. The job that oxytocin continues to do provides milk for man.

When a woman feeds her baby, very often both breasts start dribbling simultaneously. This happens because oxytocin travelling the blood stream reaches both breasts simultaneously. The apparent imperfection is perhaps a desirable phenomenon in many animals. Many species have a large litter and multiple breasts. Simultaneous expulsion of milk from all the nipples helps them in feeding all the babies at the same time.

In view of the large number of hormones produced by the pituitary, and the fact that it influences many other endocrine glands, it has traditionally been called the master gland.

CHAPTER 11

NERVOUS SYSTEM : THE TELEGRAPHIC SYSTEM OF COMMUNICATION AND COORDINATION

In the last chapter we studied the system of chemical messengers that coordinate the activities of various parts of the body. The chemical is like a letter, written by the endocrine organ, posted into the blood stream, and read by the target organ. That is why it was designated the postal system. This system takes time to get started and to produce its effects. Once switched on, its action cannot be switched off instantaneously. The present chapter deals with another system which is prompt and can be switched on or off at very short notice. It is this system that makes the mouth water as soon as there is sight, smell or even thought of tasty food, and quickens the heart beat as soon as physical exertion is anticipated. This system is also responsible for all our logical and abstract thinking. The communication of messages in this system is through solid white cord-like structures called nerves. This system is called nervous system. Messages are conveyed along nerves in the form of electrical impulses which seem to jump from one point on the nerve to the next in a systematic manner. The frequency and pattern of impulses seem to form a code which can be decoded by the recipient structures. Not only the rapidity with which the messages are conducted in nerves, but also their coding in a manner somewhat akin to the Morse code, have prompted the comparison with the telegraphic system.

Nerves constitute the peripheral nervous system in contrast to the brain and spinal cord which together constitute the central nervous system. Brain is located inside the hollow of the skull. Spinal cord is housed in the canal that runs through the backbone (vertebral column). All parts of the nervous system are interconnected. In fact, brain continues into the spinal cord;

and nerves arise from the brain or the spinal cord (Fig. 39 & 40).

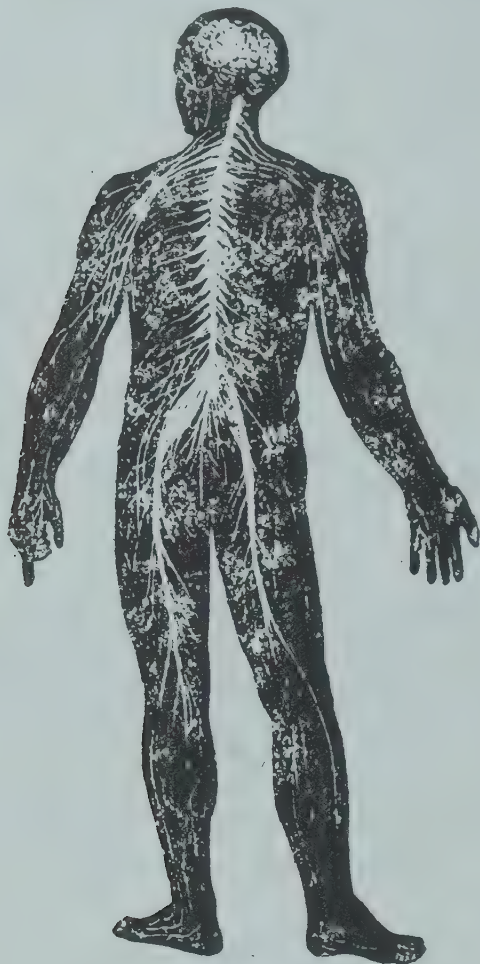


Fig. 39 The brain and spinal cord (central nervous system) and spinal nerves (peripheral nervous system). Reprinted from Miller MA, Drakontides AB, Leavell LC. Kimber—Gray—Stackpole's Anatomy and Physiology. 17 Edition, 1977. Fig. 9-2, p. 200. Courtesy: The Macmillan Co., New York, U. S. A,)

Just as the structural unit of the kidneys is a nephron, the structural unit of nervous system is a *neuron* (Fig. 41). In order

to meet its specialized function, the neuron assumes a characteris-

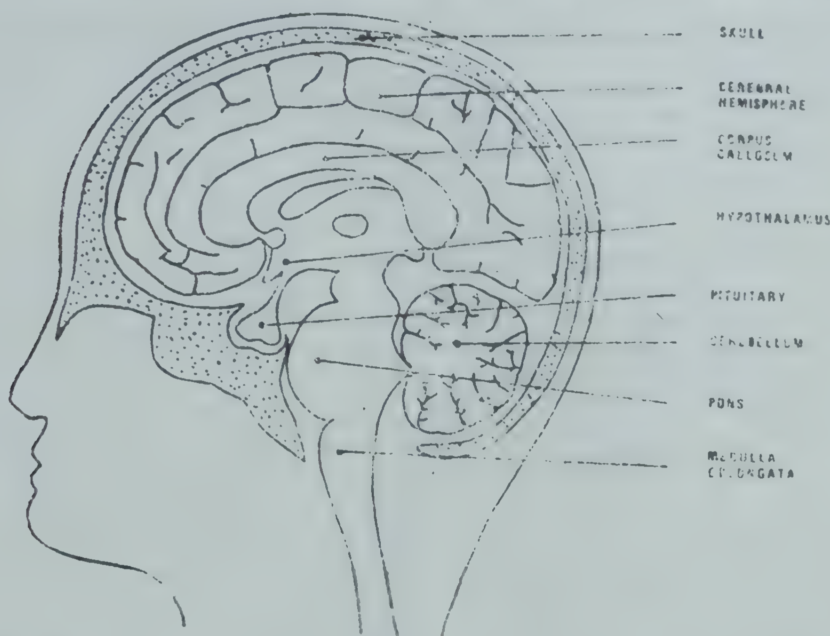


Fig. 40 A simplified side view of the human brain, split open along the middle.

tic form while still retaining some basic features of a cell. It has a nucleus and cytoplasm, forming the cell body. The cell body has elongated extensions of cytoplasm. Those extensions which are specialised for transmitting messages to the neuron are called dendrites, and the extension that transmits messages from the neuron is called an axon. The cell bodies of most neurons are located in the central nervous system.

Neurons are interconnected with each other forming a complex network (Fig. 42). In order to resolve the complexity of neuronal network one might start with simple chains of neurons which accomplish a reflex action. A reflex action, or simple, a reflex, is a fundamental function of the nervous system. Although the term reflex* is used quite commonly, it is pertinent here to describe it rather precisely. Reflex actions are involuntary, inborn and stereotype responses to stimuli mediated by the central nervous system. That a reflex is involuntary implies that it takes place

*Since reflexes are involuntary, the part of the central nervous system called cerebral cortex, which executes voluntary activities, does not mediate reflexes. In other words, reflexes are mediated by levels of central nervous system lower than the cerebral cortex.

irrespective of will-power. No deliberate or conscious action is involved on the part of the individual displaying the reflex action. That a reflex is inborn implies that it does not have to be learnt. That does not mean that all reflexes are present at birth. Many of

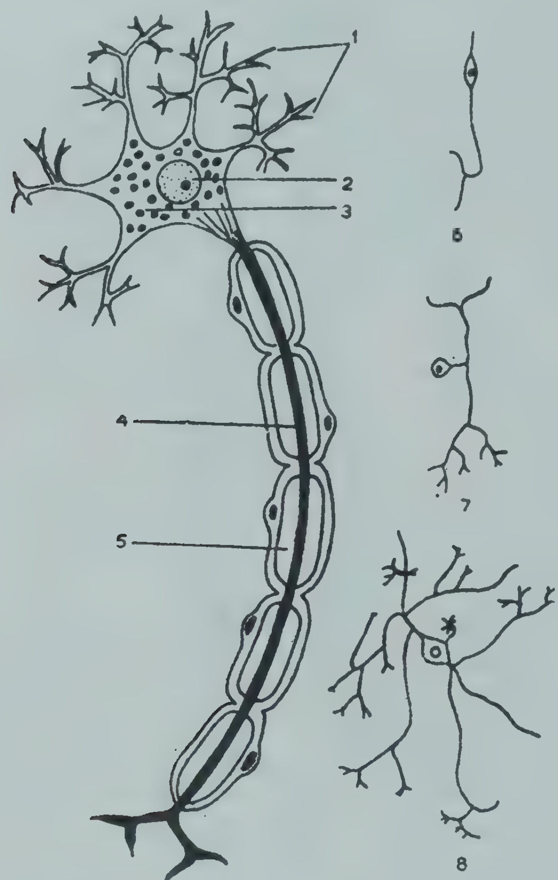


Fig. 41 Diagram of the structure of a nerve cell (neuron) showing dendrites (1), nucleus (2), cytoplasm (3), axon (4), and myelin sheath (5), Although a 'typical' neuron is usually drawn as depicted in the detailed diagram on the left, neurons can assume a wide variety of shapes. Some such shapes are shown on the right (6—8).

them appear later without being taught. On the other hand, some reflexes, for instance the suckling reflex, are present at birth but disappear later. Some reflexes, such as micturition and defaecation reflexes, are present at birth, but get modified by superimposition of voluntary control that develops later. That a reflex action is

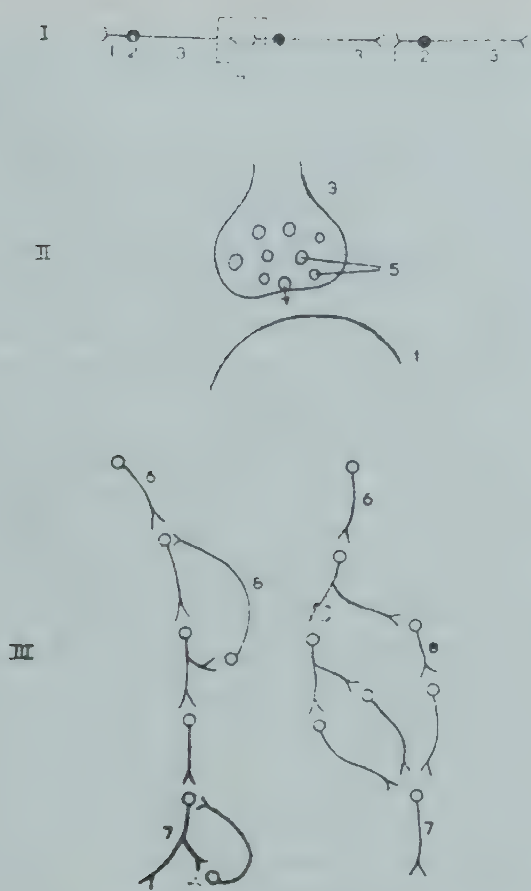


Fig. 42 Inter-neuronal communication.

I. Diagrammatic representation of a chain of three neurons. 1, dendrites; 2, cell body; 3, axon; 4, synapse (junction between two neurons). (For further simplification, dendrites are also usually omitted as in III).

II. Neurons communicate with each other at synapses by releasing a chemical (neurotransmitter) at the terminal end of the axon (3). The neurotransmitter is contained in balloon-like sacs called vesicles (5). During the process of communication, a small quantity of the neurotransmitter is released in the gap between the axon and the dendrite (1) of another neuron.

III. Neurons form complex networks, some idea of which may be had from two extremely simple ones depicted here. For simplicity, the dendrites have been omitted. The effect of exciting neuron 6 on the activity of neuron 7 could differ depending on whether neuron 8 is excitatory or inhibitory.

stereotype in nature implies that so long as the stimulus is the same, the character of the response is exactly the same on all occasions. Not only is it uniform in a given individual, its pattern is quite similar throughout a species, and quite often, even in many related species. For example, if a finger is pricked with a pin, the invariable response is withdrawal of the hand by flexing (bending) the arm. Every time the finger is pricked, the response is the same. That does not, however, mean that a reflex cannot be modified or extended by learnt behaviour. For example, if a man steps on a piece of burning coal, the reflex response is to jump off the piece, but the subsequent behaviour is voluntary, learnt, and will therefore vary with the nature of the individual and the circumstances involved. He may move the coal aside so that anybody else is unlikely to repeat his experience, or he may pour some water over it with the same motive, or he may just leave it there and walk on. It is not certain what the reflex response to a slap is, but the learnt response could vary from returning the slap to offering the other cheek.

The chain of neurons that participates in a reflex action is called a reflex arc (Fig. 43). It consists of at least two neurons. One of them (sensory or afferent neuron) conveys the information about the stimulus to the central nervous system. The other(motor or efferent neuron) conveys the message from the central nervous system to the organ (effector organ) which has to respond to the stimulus. There may be one or more neurons (interneurons) interposed between the sensory and motor neurons. The more the interneurons, the more complex would be the processing of the information received by the central nervous system, and correspondingly, the decision or instructions conveyed to the effector organ would also be more complex. The complexity is increased by the fact that all these interneurons do not stimulate the neuron (s) they impinge on. Some of them actively inhibit the neuron (s) within their sphere of influence.

A few examples of reflexes have already been cited. Innumerable other reflexes are going on within the body. Only some of them are the type in which the stimulus and the response are both obvious. For example, when the hand is withdrawn in response to a pin prick, both the stimulus and the response are obvious and the 'performer' becomes aware of both within a few moments of

the 'performance'. The 'Involuntary' component of the act which qualified it as a reflex is that the decision to withdraw the hand is not taken at a conscious level. But in many reflexes, not only the decision regarding the nature of the response, but also the very existence of the stimulus and the response never reach consciousness. For example, the secretion of gastric juice in response to presence of food in the stomach, or the inhibition of gastric juice in response to entry of food in the duodenum are reflexes which take place without the stimulus or the response ever rea-

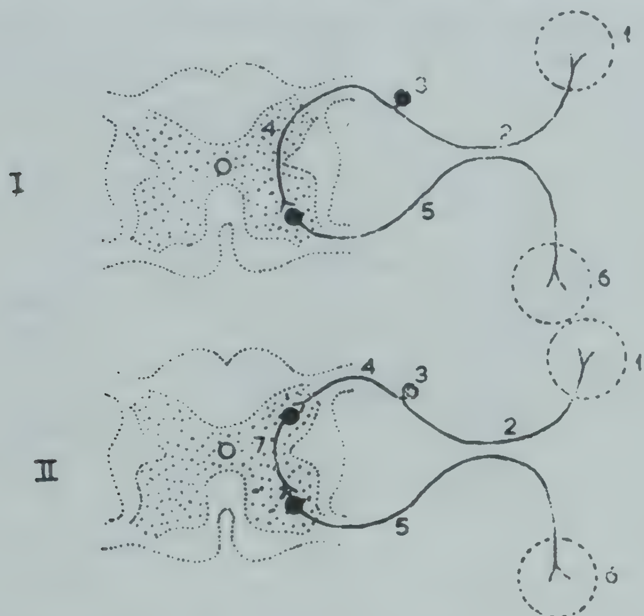


Fig. 43. Diagrammatic representation of reflex arcs.
I. The simplest reflex arc is made up of just two neurons (monosynaptic reflex arc).
II. A reflex arc made up of three neurons.
1, receptor; 2, dendrite of sensory neuron;
3, cell body; 4, axon; 5, axon of motor neuron;
6, effector; 7, interneuron.

ching consciousness. Such reflexes control the activities of the heart, respiratory system, urinary tract and reproductive organs. Their operation outside the realm of consciousness saves us the agony of taking care of so many details of the functioning of the body. It would undoubtebly be a big botheration; further, in spite of all our intelligence, we can't be trusted to voluntarily control the tempo of activity of all our internal organs and keep it in tune with the requirements of the body. The division of the ner-

vous system that controls the involuntary activities of the body is called *autonomic nervous system.* The afferent limb of the autonomic reflexes may be stimulated by stimuli arising outside the body, for example, heat, cold or a pinprick; or inside the body, such as changes in the glucose, oxygen or acid concentration of blood. The efferent limb of autonomic activities has some unique features, and therefore deserves an elaborate description.

Autonomic nervous system

Autonomic nervous system is customarily divided into sympathetic and parasympathetic. The efferent nerves of both these

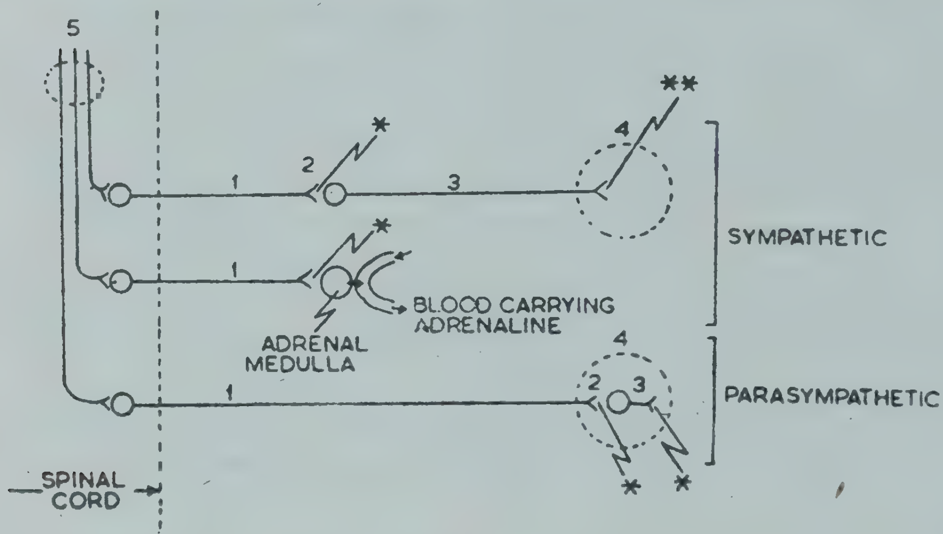


Fig. 44 The structural and functional features of sympathetic nerves, adrenal medulla and parasympathetic nerves compared and contrasted.
1, preganglionic neuron; 2, ganglion; 3, postganglionic neuron (notice how short it is in the parasympathetic since the ganglion is in or close to the organ innervated); 4, the organ innervated by sympathetic or parasympathetic nerves; 5, higher influences from the brain affecting autonomic outflow.
*, acetylcholine released as neurotransmitter;
**, noradrenaline released as neurotransmitter.
Note that the adrenal medulla is a modified sympathetic ganglion. Its cells act like postganglionic neurons, but release adrenaline directly into the blood stream.

divisions are located in the central nervous system, but they do not innervate the organs directly. They communicate their message through another neuron. The junction between the two neurons

is called a ganglion (Fig. 44). In general, the post-ganglionic fibre, is extremely short in case of the parasympathetic division.

The effects of the sympathetic division are beneficial in an emergency or stressful situation. It is only appropriate that an arrangement which helps in an emergency is considered 'sympathetic'. On the other hand, in a relaxed state, parasympathetic activity predominates. Parasympathetic effects are generally opposite the sympathetic effects, but they cannot be considered unsympathetic, since they are the most beneficial in the circumstances in which they occur. Organs innervated by autonomic nerves usually receive both parasympathetic and sympathetic nerves,

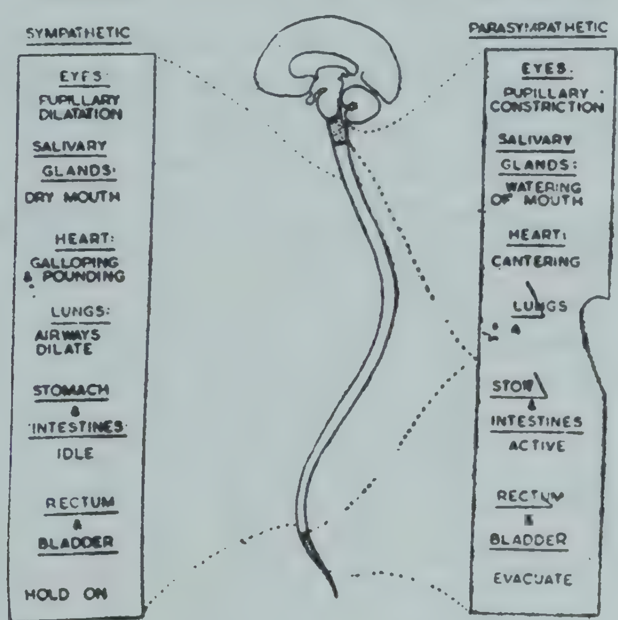


Fig. 45 The parasympathetic outflow is from the brainstem and the tail end of the spinal cord (dotted areas). The sympathetic outflow is from a considerable length of the middle of the spinal cord. The effects of sympathetic and parasympathetic activity on some organs of the body have also been shown. Note that they are essentially opposite in character. The sympathetic effects are useful in an emergency, and the parasympathetic effects are desirable when one is at peace.

which modulate their activities in opposite directions. With the above background, it is easy to predict the sympathetic and parasympathetic effects on various organs (Fig. 45). For

example, in an emergency, a person may need to run, and that would require vigorous action of the heart and vigorous breathing. Accordingly, sympathetic nerves increase the rate and pace of contraction of the heart and dilate (open up) the airways. On the other hand, one would like to read only in a relaxed state. Correspondingly the pupils constrict to make near objects clearer as a result of parasympathetic activity; sympathetic stimulation dilates (widens) the pupils.

It would be appropriate to ingest and digest food, defaecate or urinate only in a relaxed state. Accordingly, gastrointestinal motility and secretions, and rectal or urinary bladder contractions are stimulated by parasympathetic activity. The sympathetic activity does just the opposite. The remarkable thing is that while parasympathetic stimulates rectum or urinary bladder, it relaxes the sphincters so as to facilitate evacuation, while sympathetic has opposite effects (Fig 46). Thus the actions are in terms of functional utility, rather than contraction or relaxation.

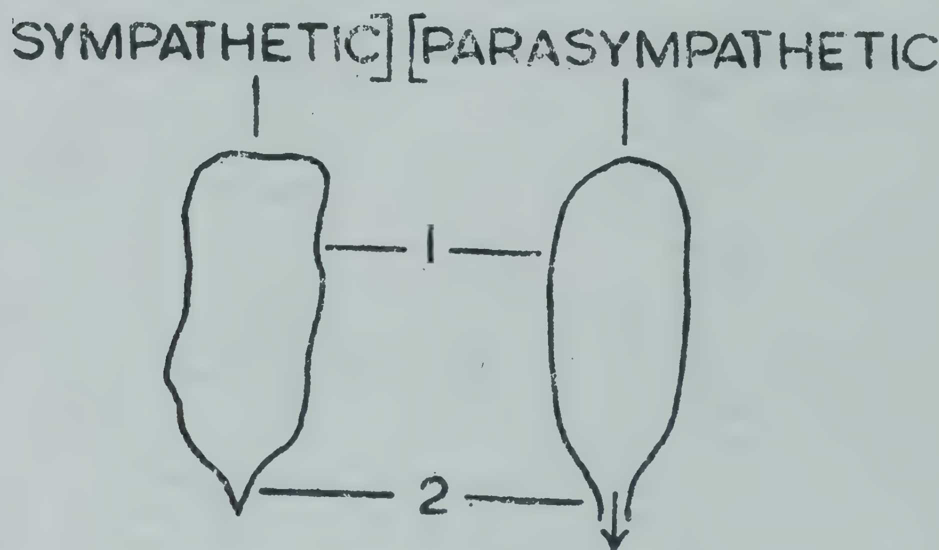


Fig. 46 Effect of autonomic nerves on hollow organs like the urinary bladder or rectum. Sympathetic nerves relax the organ (1), but close the sphincter at the opening (2) tight thereby permitting storage. Parasympathetic nerves make the organ contract but relax the opening, thereby facilitating evacuation.

One might ask why there need be two sets of nerves for every organ. For example, what is the need for having parasympathetic nerves to slow down the heart, and sympathetic nerves to quicken

the heart; for example, if there were only parasympathetic nerves, their stimulation would slow down the heart, while lack of their stimulation would quicken the heart. Thus both functions, viz. slowing and quickening, could be served by only one set of nerves. To understand the advantage of two sets of nerves, a useful analogy is that of automobiles, all of which have both accelerators and brakes. Although, it is possible to slow down a vehicle by discontinuing the use of the accelerator, more effective slowing can be achieved by using the brake in addition.

At any given moment in the relaxed state, one will either only eat or read or defaecate, and therefore, pronounced parasympathetic effects are usually confined to the region involved, although the predominant tone may be parasympathetic throughout the body. On the other hand, in an emergency, sympathetic effects are observed throughout the body, because they all cooperate and coordinate to equip the body better to face the situation. For instance, a rise in heart rate and force of contraction of the heart, facilitation of rapid and forceful breathing, suspension of gastrointestinal and urogenital activity, and elevation of blood glucose are all required simultaneously to fight any type of emergency better. Not only is there an outpouring of sympathetic nerve impulses throughout the body, there is also simultaneous release of adrenal medullary hormones, adrenaline and noradrenaline (Chapter 12). The overall effects of adrenal medullary hormones and sympathetic activity are similar, because postganglionic sympathetic nerve fibres also release noradrenaline. The sympathoadrenal reaction, as the combined reaction is called, seems to have evolved in animals who have to frequently fight an enemy or catch a prey for their very survival. Therefore the reaction was christened the 'fight, flight or fright reaction' by the eminent physiologist, Walter Cannon, at Harvard Medical School in the early twentieth century. The full-blown reaction is seldom required in the 'civilized' man, but continues to be observed as a hangover from our evolutionary past. Further, civilised behaviour requires that we suppress many aspects of this reaction deliberately. For instance, we often cannot spank or run away from the source of our anger. The result is that our sympathoadrenal reaction mainly serves to raise our heart rate, blood pressure and blood sugar, without these changes being put to any use. If such reactions are all too frequent in a person he

may develop a persistently high blood pressure. Such a person would have his autonomic balance permanently tilted towards the sympathetic. In contrast, Yogis and others with calm and meditative personalities have a parasympathetic tilt in their autonomic balance. They are less prone to develop the diseases of modern civilization like high blood pressure or heart disease.

Reflexes and autonomic functions are relatively basic activities of the nervous system, which are subject to control by higher levels of the central nervous system. In addition, the higher centres of nervous system are also the structural basis of intelligence, memory, discrimination, abstract thinking and such other intellectual functions. We shall talk about some of these functions in subsequent chapters. To a limited extent one might say that the more highly evolved an animal is, the more elaborate is the higher control superimposed on basic neural functions. Among men also, people who cultivate a stronger voluntary control over basic biologic urges like hunger, thirst, anger or sex, and those who have better developed intellectual functions, are considered more civilized. Like everything refined, the higher neural functions are also the more delicate ones. They are the first ones to be knocked out by any substance that numbs the nervous system. One such substance is alcohol.

Contrary to popular impression, alcohol is not a stimulant for the brain. It depresses brain functions, the most susceptible being the higher functions like intelligence and discrimination. The result is that the restraint that normally keeps basic and baser instincts under check is lifted, and the person becomes elated, garrulous and rowdy. Thus the apparent stimulation is the result of inhibition of an inhibitory influence. With still larger quantities of alcohol, consciousness is also impaired, and finally the most basic and most resistant functions such as cardiac and respiratory centres are also depressed. When that happens, the individual dies. Only rarely does a person drink himself to death, although it is possible to do so.

Some specific issues related to the nervous system will be discussed in the next few chapters.

CHAPTER 12

MUSCLES AND JOINTS : A MOVING STORY

Lungs replenish the oxygen consumed by the body and get rid of the carbon dioxide produced by it. But in order to do so, they have to be expanded and squeezed alternately. The heart pumps blood by filling and emptying alternately. The stomach sends the food to the intestines by pushing it further. We lift a weight, or walk from one place to another, by using our limbs. One phenomenon that is common to all these activities is motion, and the structure that brings about motion is called muscle. The fundamental property of muscle tissue is contraction. At molecular level, all contractile tissues have at least two proteins—actin and myosin—somewhat erroneously called contractile proteins. The nomenclature is misleading because the proteins do not contract, but merely get rearranged every time the muscle contracts or relaxes.

Muscles are conventionally categorised into three varieties—cardiac, smooth and skeletal. Cardiac muscle is the muscle of the heart. Its function is a part of the working of the heart (Chapter 6). Smooth muscle is the muscle of internal organs, such as the stomach, intestines, urinary bladder, blood vessels or uterus. All these parts of the body have been discussed in relevant chapters. Cardiac muscle and all smooth muscle share one common feature, i.e. their action is not under the control of will power. That is why they are spoken of as involuntary muscles. They have a certain degree of inherent activity, which is further modulated by autonomic nerves (Chapter 11). In contrast, the third variety of muscles, the skeletal muscles, are under the control of will power, and are therefore spoken of as voluntary muscles. It is these muscles that we employ to throw a ball or to climb the stairs as and when we like. Their nerve supply is also somewhat differently organized. Moreover, voluntary muscles have no

inherent activity. Their activity is entirely dependent on their nerve supply. When the nerve supplying a voluntary muscle is activated, the muscle contracts. As soon as the nerve activity ceases, the muscle relaxes. The rest of this chapter deals only with skeletal or voluntary muscles.

Skeletal muscles are the muscles that one ordinarily thinks of when talking about muscles. Biceps, triceps and all the other muscles that give our body its contours are skeletal muscles. Besides big muscles that enable us to run and dance, muscles of the face that reveal our feelings are also skeletal muscles, as are also the

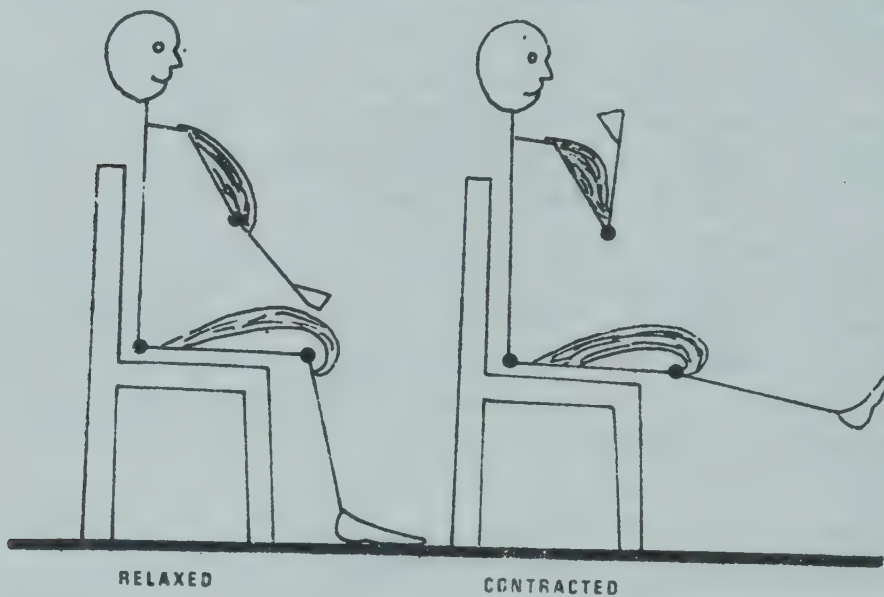


Fig. 47 Skeletal muscles are attached to bones and always cross a joint. The position of the attachments and the nature of the joint determine the type of movement brought about by activity of the muscle.

muscles of breathing. All these muscles are called 'skeletal' because they are attached to bones (the skeleton) at either end. In fact, muscles taper into tough whitish cord-like structures called tendons which, in turn, are attached to bones. One thick round tendon which we are all familiar with is at the ankle near the heel. The two ends of a skeletal muscle are always attached to two different bones. In other words, a skeletal muscle always crosses a *joint* between two bones. The positions of the bony attachments determine the nature of the movement a muscle brings about when it contracts (Fig. 47).

The equivalent of a cell in a muscle is a muscle fibre (Fig. 48). Unlike other cells, a muscle fibre has a large number of nuclei. If we examine a muscle fibre under the microscope, it is found to be a bundle of myofibrils. Each myofibril shows alternate dark and light zones or bands. The dark and light bands of different myofibrils in a muscle fibre are arranged in such an orderly fas-

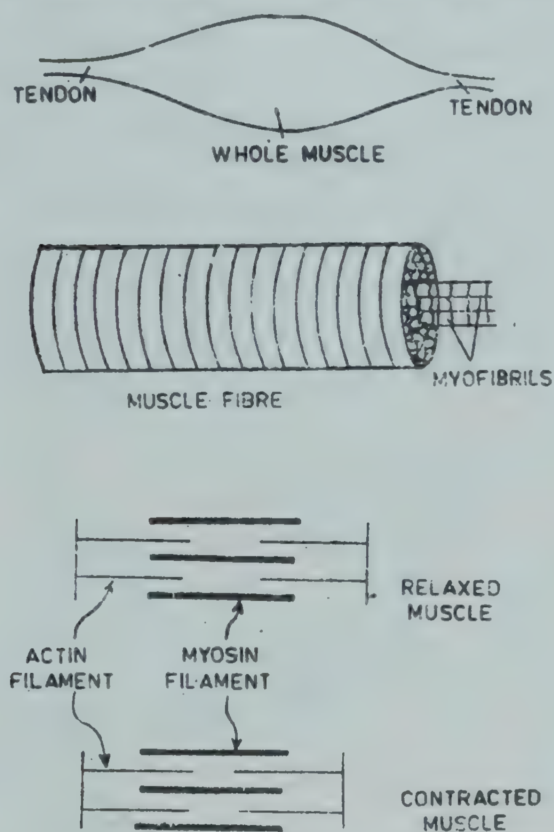


Fig. 48 A muscle (top) is made up of a large number of muscle fibres. Each muscle fibre is made up of several myofibrils, which in turn have in them very neatly and regularly arranged myofilaments of two types—actin and myosin. Sliding in of actin filaments accompanies contraction.

hion that a muscle fibre as a whole also appears to have alternate dark and light zones. This gives the muscle fibres an appearance of being striped or 'striated'. That is why skeletal muscles are also called striated muscles. If we magnify a myofibril further, we can see in it two types of myofilaments arranged in a geometrical fashion. The two types of filaments are made up of the proteins actin and myosin. Actin filaments are thin, and make up the

light bands; myosin filaments are thick, and make up the dark bands. When a muscle contracts, the thin filaments slide in while the thick filaments stay where they are (Fig. 48). That is how the muscle as a whole gets shorter.

It was mentioned in passing earlier that voluntary muscles contract only when their nerve supply is activated. Each skeletal muscle is supplied by at least one nerve. Just as the muscle is made up of muscle fibres, the nerve is made up of nerve fibres. On entering a muscle, each nerve fibre branches out and supplies a few muscle fibres. The more the nerve fibres are activated, larger will be the number of muscle fibres activated simultaneously. That is how the force of contraction is altered. The nerve fibres supplying a voluntary muscle are, in fact, the axons of nerve cells (neurons), the cell bodies of which occupy a small well-defined niche in the spinal cord (Fig. 49). This particular site of the spinal cord is

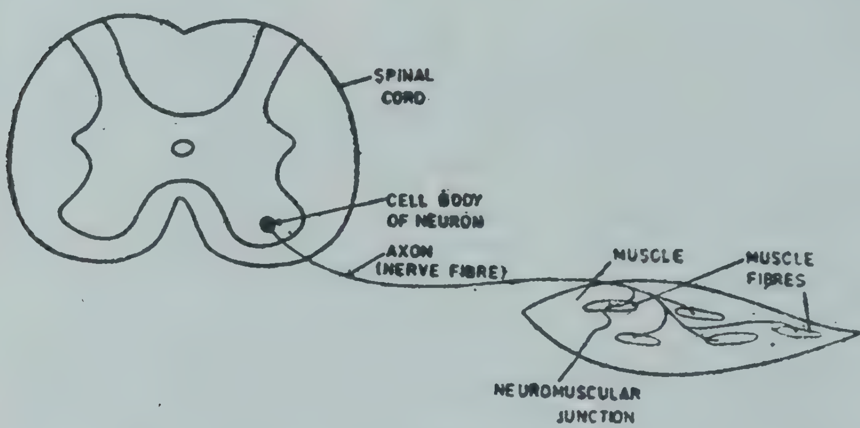


Fig. 49 Muscles are supplied by nerve fibres originating from neurons, the cell bodies of which occupy a specific corner in the spinal cord. One nerve fibre generally supplies a large number of muscle fibres.

damaged in polio leading to paralysis of muscles. The activity of these cells of the spinal cord is further modulated by various regions of the brain, including the highest, viz, the cerebral cortex. Cerebral cortical control makes voluntary movements possible, and also imparts accuracy and delicacy to the movements.

The next question that arises is how the nerve fibres tell the muscle fibres to contract. The message is conveyed along the nerve fibre in the form of a propagated electrical impulse. At the

place where a nerve fibre meets a muscle fibre (neuromuscular junction), the nerve fibre expands and rests like a foot (Fig. 50) The expanded terminal contains a large number of tiny balloon-like structures (called *vesicles*) containing acetylcholine. When electrical impulses travelling along the nerve fibre reach the terminal, acetylcholine is released in the narrow space between the nerve and the muscle. Acetylcholine induces electrical activity in the muscle, which, through a series of events, leads to sliding-in of thin filaments, and consequently, muscular contraction. From

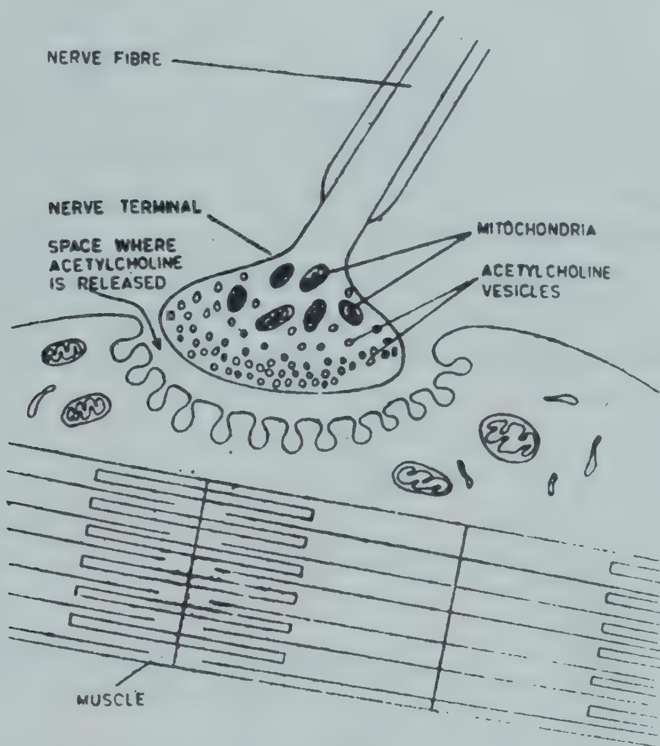


Fig 50 The nerve ending terminates very close to a muscle fibre in the form of a swollen structure. Neuromuscular junction is a specialized region for efficient transmission of nerve impulses to the muscle fibre.

the above account, and some earlier chapters, it is evident that the activity of all excitable tissues, i.e. nerves and muscles, is associated with electrical activity. Just as the record of electrical activity of the heart is called an electrocardiogram (ECG), the record of electrical activity of muscles is called an electromyogram (EMG). EMG is useful for diagnosing and tracing the progress of several disorders of muscle.

Excessive use of a skeletal muscle makes it stronger and enlarges its size, which is due to an increase in the size of the individual muscle fibres. On the other hand, not using a muscle induces disuse atrophy. Physical exercise not only makes muscles stronger but also brings about favourable changes in circulatory and respiratory systems so that a trained person can undertake physical exertion with greater ease. Prolonged and continuous use of muscles for such activities as walking or cycling makes the muscles and their tendons painful. But they recover after a period of relaxation.

Our 'moving story', or story of movement, would not be complete unless we talk about the *joints* which are, literally, at the centre of every movement. Joints are an engineering marvel—several mechanical devices work in a manner similar to joints but perhaps none is as good. Some joints, such as the shoulder or the hip joint, are of the ball and socket variety; some others, such as the elbow and knee, are of the hinge variety. Joints are not mere approximation of two bones—they come complete with

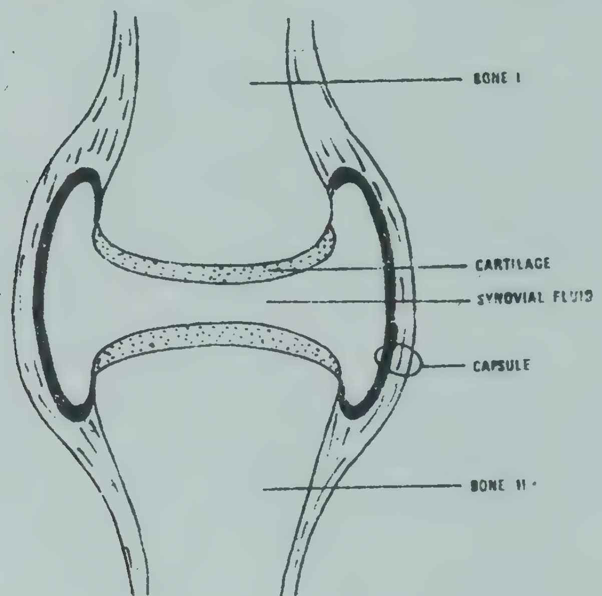


Fig. 51 The structure of a typical joint. The two bones involved are separated by cushion-like cartilages which act as shock absorbers, and the synovial cavity filled with a fluid which acts as a lubricant.

appropriate cushions (cartilages) and lubricant (synovial fluid) (Fig. 51). As a result, they work so silently for decades that we

take them for granted. But sooner or later, they do complain. It is rare to find an adult who has never had pain in the joints. Some simple principles can help us prevent and ameliorate common forms of joint pain.

The commonest joint pain in India is osteoarthritis. It essentially results from the effects of wear and tear, but the predisposition to get it seems to be inherited. Although one cannot chose one's parents, it is possible to reduce wear and tear. An overweight person imposes a heavy burden on his joints. That is the reason for osteoarthritis being the commonest in weight-bearing joints such as the knee. That is also why overweight persons are more prone to get osteoarthritis, and patients having it are advised to lose weight. Secondly, muscle contraction around a joint protects it from part of the weight acting on it. That is why patients are advised exercises for strengthening of muscles, and persons with strong muscles are unlikely to get joint pains. Osteoarthritis is a mild, non-crippling disease. But there are several other types of joint diseases, in which not only there is pain, but also redness and swelling of the joints. One of the commonest of these, rheumatoid arthritis, can eventually lead to severe disability. However, in view of the large variety of joint diseases, instead of getting alarmed, it is better to seek proper medical advice. Because of the chronic and intractable nature of joint diseases, they provide a fertile field for quacks and charlatans. But visiting them often consumes time and money without giving commensurate benefit, and may sometimes do more harm than good.

One series of joints deserving special mention is the back. Backache is one of the commonest symptoms after middle age, and is largely preventable if the underlying physiology is understood. The backbone is made up of a row of ring-like bones, called vertebrae. If a man lifts a heavy weight, which may well be half his own weight, the pressure on the vertebrae can exceed what the soft cushions interposed between successive vertebrae can stand. The reason why a normal individual is able to lift weights is that while doing so there is a reflex contraction of muscles of the rib cage, belly and back. This converts the chest and abdomen, including the back bone, into a rigid cylinder. With an increase in area sharing the load, the stress on the

backbone drops by 30-50%, thereby making it easily bearable. The impact of area on pressure can be understood from a simple example. If a person stands on sand, his feet sink in, but if the same person lies down on the same sand, he hardly makes a dent. The reason is that his body weight exerts a much greater pressure on sand in the standing position than in the lying down position because the area in contact with the sand is much larger in the lying down position.

The key to a healthy back, therefore, is to have such healthy abdominal and back muscles that the chest and abdomen behave like a rigid cylinder sharing as one unit the weight imposed on the back.

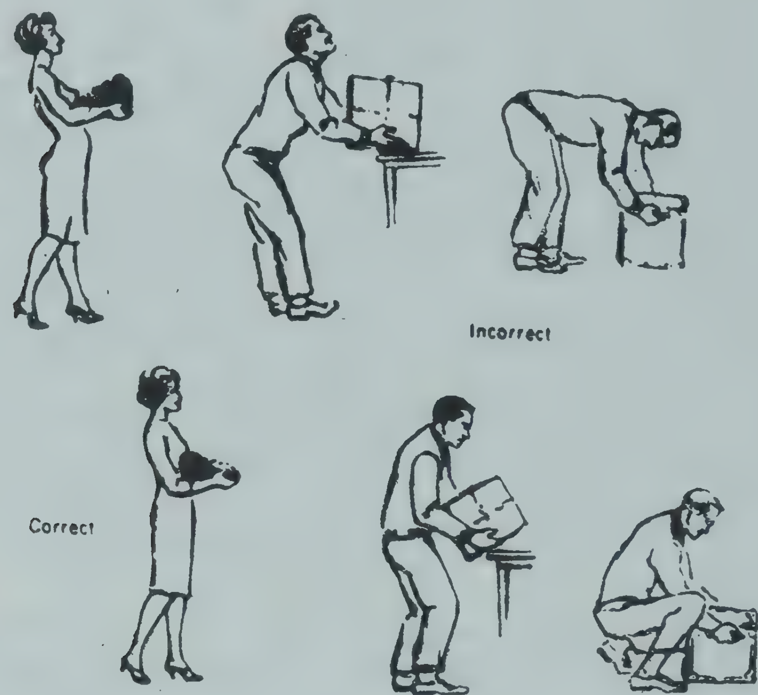


Fig. 52 The incorrect and correct ways of lifting weights. The incorrect ways are needlessly cruel to the back.
(Reprinted with permission from Astrand, P.-O. and Rodahl, K. Textbook of Work Physiology. 1970. Fig. 8-11. Courtesy: Mc Graw Hill Book Co., New York, U.S.A.).

Based largely on the principles discussed above, following are a few rules for preventing problems with the back :

1. Keep good posture.

2. Avoid shoes with high heels.

3. Avoid unaccustomed weight-lifting and sudden movements of the back.

4. Lift weights the correct way (Fig. 52).

5. Do not try to lift, push or pull when off balance, or while turning or twisting. One should arrange the situation in such a way that one is standing on a secure foundation facing the direction of movement before picking up a load.

6. Keep abdominal and back muscles in good shape by appropriate exercises—swimming is one of the best; walking or running upstairs or uphill are also good for the trunk muscles.

Muscles and joints do not contribute to life processes the way lungs or kidneys do. But their contribution to survival is indispensable. No animal can survive if it cannot move about to to find its food; human societies are able to support only a small number of paralysed individuals rather imperfectly. Nature, in its supreme wisdom, has therefore given muscles about half a man's body weight.

CHAPTER 13

PAIN

Pain is an intensely personal unpleasant experience. Language is an inadequate medium for communicating it to others. Pain disrupts normal behaviour. It inhibits learning, induces aggression and erodes the entire personality. Even when only one part of the body like the head or the eye pains, the whole person suffers, as Prophet Mohammed put it. There are two aspects of pain-awareness of a painful experience and the reaction to it. In the presence of a cause for pain, almost everybody is aware of pain, but the reaction to it is highly individualized. Even the same person does not react to pain in the same way all the time.

Pain is essential

Pain is bitter, but not having it can be worse. Rarely, children are born who do not feel pain. Only about twenty such cases have been reported in the medical literature so far. One famous report is that of a 54 year old "Human Pincushion" who had experienced 'pain' only thrice in his life : at the age of 7 he had a headache for a few days after an axe was buried in his skull; at the age of 14 he felt pain "for an instant" when a surgeon probed his finger for a bullet; and at 16, he felt hurt when his broken bone was being set. However, such individuals lead far from happy lives. As is seen from the above description, this man met with serious accidents rather frequently quite early in life. This is because children like to explore their surroundings extensively and often dangerously. Sometimes the only limit to their mischief is pain. Therefore, children congenitally insensitive to pain often inflict severe injuries on themselves and die early in life. They are known to chew off their fingers and tongue, pick off their nares, lean against lit stoves, and sit in scalding baths. There is on record one such 3½ year old boy who liked to play with fire, received frequent blisters and burns but laughed at them, liked to hit his head and frequently pulled

out his teeth. Thus pain is an important protection against injury. It warns us about impending tissue damage and motivates us to get rid of the damaging agent. The chest pain of heart disease, the headache of high blood pressure, the tooth ache and the tummy ache are all useful signals which drive us to seek a cure. Occasionally, however, pain is an unnecessary and unfortunate byproduct of a disease process. For instance, the pain of cancer often comes late — usually after the disease is incurable, and then it merely adds to the misery and helplessness of the patient as well as his well-wishers.

How pain is felt

Tissue damage results in some chemical changes which are able to stimulate nerve endings which, in turn, carry the sensation of pain towards the brain. These nerve fibres are of two types — thick and thin. The thick fibres transmit messages faster, the information is better localized, and the pain felt is of the pricking type. In contrast, the thin fibres transmit slowly a diffuse burning type of pain. Skin is supplied with both these types of nerve fibres. That is why when a finger gets a cut with a blade, the pain felt first is of the pricking type, which is sharply localised along the line of the cut. But soon this pain is overshadowed by a diffuse burning pain which appears a little later due to the slower conduction in thin fibres. This burning pain is much more distressing than the initial pricking pain. Further, the thin fibres are more susceptible to local anaesthetics, while the thicker fibres are blocked more easily by pressure. That is why, when a surgeon drains a boil under local anaesthesia, the patient can feel the pricking motion of the knife, but not the burning pain. He often tells the surgeon, "I can feel you are working on me, but it doesn't hurt me." On the other hand, when the finger gets caught in a door, one reflexly squeezes the finger with the other hand. The pressure takes away the pricking pain completely but the burning pain still persists. These two types of pain are felt only superficially on the skin. Pain from deeper parts of the body like the muscles, heart or stomach is only a dull, aching or burning, poorly localized pain.

Besides the stimulation of specific pain nerve endings, intense stimulation of any nerve ending gives rise to pain. That is why excessive pressure or a very hot or cold object also produce pain.

Stimulation of the peripheral pain receptors is a relatively simple affair. The actual perception of pain is far more complex. Every painful stimulus is not allowed to be transmitted to the brain with equal ease. To some extent, it depends upon the competition offered by other stimuli. That is why a child who hurts his thumb blows at it and sucks it. These additional stimuli partially prevent pain impulses from reaching consciousness. For the same reason, painful sites hurt more at night when, unlike during the day, there are very few external stimuli to keep us engaged. Irrespective of other stimuli, if the painful stimulus continues at a monotonously uniform intensity for a very long time, it becomes less effective. As Ghalib has said, "Ishrat-e-katra hai dariya mein fana ho jana, Dard ka hud se guzarna hai dava ho jana." (A drop of water loses its identity when it becomes a part of the river; similarly, when the intensity of pain crosses a limit, the pain itself becomes an analgesic). Further, the intensity with which pain is perceived as well as the reaction to it are affected by the state of the brain. Thus an anxious person feels more pain than a relaxed person. Soldiers wounded badly have often denied pain because of the accompanying happiness over having fought bravely for a good cause, and the relief of escaping alive. The personality of the individual also affects the reaction to pain. The reaction varies from "Look, how much I suffer", to "Look, how brave I am". The cause of the pain also affects the emotional disturbance it produces. Self inflicted pain as a penance and pain suffered in the process of fighting for a noble cause are often tolerated very happily. A pain in the chest which the patient believes to be originating in the heart is much more distressing than pain of the same intensity in the leg which has less dangerous consequences. The response to pain also varies with accompanying circumstances. If hot tea is picked up in an *expensive* cup, chances are that the cup will not be dropped in response to the pain. Rather, one is likely to replace the cup quickly on the table and shake the hand. Past experience is another important factor influencing the suffering a pain produces. A child starts crying at the very sight of a syringe because past experience has taught him that the appearance of a syringe on the scene is an announcement for an injection, and an injection causes pain. On the other hand, a minor pain can disappear in anticipation of a bigger pain. As John Webster, a 17th century playwright, wrote, "the tooth

ache disappears at the sight of a barber that comes to pull it out".

The influence of past experience is best illustrated by the phenomenon of phantom pain. In patients who have undergone amputation, for a few weeks or months, and sometimes even for years, there is a feeling as if the lost limb is still present — it feels stretched, warm, cold, wet and sometimes even painful. This is because the brain still interprets impulses coming from the nerves of the limb as coming from the limb, even though the limb is no longer there.

Relief of pain

Pain is the commonest symptom a doctor is called upon to treat. The best treatment of pain is to cure the cause of the pain. If that is not possible, or is likely to take long, then the pain itself has to be treated. In the ordinary course, drugs are able to take away the pain. The commonest drug used is aspirin, which, though 100 years old, is as good or as bad as any of its latest competitors. Its occasional use does no harm to most people. However, prolonged, excessive and habitual use can cause kidney damage, bleeding from the stomach, and deafness. Its most popular and frequent use is for headaches. In view of its toxic effects, its use should be curtailed, and headaches treated by reducing the stresses and strains of life to a level one can comfortably cope with. There are situations when aspirin is not enough or is not the most suitable drug. In that case, other drugs are used.

Occasionally, drugs do not succeed in relieving pain, or they are inconvenient. Then various surgical procedures are performed depending upon the situation. Surgical methods vary from the simplest like blocking a nerve with an injection of alcohol, to the most complicated like destroying small calculated areas of the brain. Destruction of certain areas of the brain abolishes perception of pain, while that of other areas merely takes away the unpleasantness of the pain, leaving the awareness of pain intact. After such an operation the patient says, "Yes, the pain is there. But I don't care."

CHAPTER 14

EMOTIONS

A man is more than a thinking machine. He has a sensitive mind which feels joy and sorrow, anger and pleasure, disappointment and fulfillment. All these feelings are emotions. Without emotions our mental life would be dull and colourless. We would miss the fun of a good joke, the suspense of detective fiction and the thrill of solving a difficult problem.

Emotions are not just a part of mental activity but also have important physical accompaniments. Who has not felt the mouth going dry while waiting for an oral examination, or the pounding heart while waiting anxiously for a near and dear one.

Psychologists believe that every fundamental emotion has a certain pattern of physical changes associated with it. But since emotions usually are a variable mixture of fundamental emotions, in practice, the exact pattern of physical changes is different every time one gets emotional. Orders for physical changes are issued from the brain. They are carried out by those nerves which are not under the control of our will-power (autonomic nerves, Chapter 11). That is why we cannot help sweating with fear or flushing with anger. The physical changes associated with emotional reactions may be sympathetic, parasympathetic, or a mixture of both. In general, sympathetic overactivity dominates in fear, and parasympathetic in distress. In anger it is a mixture of both. The heart beats fast and the blood pressure rises. But simultaneously, there is flushing of the face and an increase in movements and secretion of the stomach. Probably this combination of activities is of importance to animals who might have to attack another animal even while they are eating. In such a situation, their sympathetic system would help them to mobilise maximum energy, while the parasympathetic activity would allow digestion to continue. A striking demonstration of physical changes during emotional fluctuations in human beings was obtained in 1940s from

studies on a healthy subject, Tom. Tom got a bullet injury in childhood which left him with a lifelong opening in the belly. The opening formed a sort of window to his stomach. Through this window, the interior of his stomach could be visually observed. Sudden fear was found to blanch his gastric mucosa while hostility and resentment led to reddening of the mucosa with increased acid secretion and motility. Sometimes such bouts of increased acid secretion in the stomach occur very frequently in ambitious, tense, sensitive, or perfectionist individuals, who are angry with the world most of the time, though often with justification. On many occasions, the acid has no food to act on. Then it acts on the wall of the stomach itself. The process could contribute to the development of an ulcer in the stomach (Chapter 7). However, ulcers do not develop in the stomachs of everyone having prolonged emotional stress. Depending upon the constitution of the individual, the person might instead get high blood pressure, or heart disease. This intimate relationship between emotional upheavals and physical misery has led man to propound so many religious and philosophical schools of thought which aim at control of emotions. Most of them encourage us to summon our will power and our reasoning to maintain a tranquil disposition in both pain and pleasure. One might question the very desirability of controlling emotions, since a lot of progress depends upon the *anger* of some individuals at the injustice, inequality, poverty, illness, and misery around them. However, no religious or philosophical doctrine is incompatible with dispassionate activity aimed at making the world a better place to live in. As the Gita teaches us, man should act, do his duty, but should remain emotionally detached from the results. This type of approach seems to ensure maximum good to others with minimum harm to one's physique. Mahatma Gandhi is a good living example of this philosophy from recent times. He felt concerned with so many problems of the world, did so much to cure them, but remained virtually free of physical symptoms.

Brain and emotions

It was mentioned in passing earlier that autonomic nerves act on instructions issued by the brain. Though the entire brain functions as one unit, there are some regions of the brain that are

more intimately involved in emotions. The area principally involved is a ring-like structure enclosing the brain stem. This ring-like area (Fig. 53) is called the limbic system (*Limbus*,. border). The limbic system is virtually the entire brain in reptiles, and is the major part of the brain in rats, rabits and cats. In man, and to some extent in monkeys, the limbic system is buried deep into

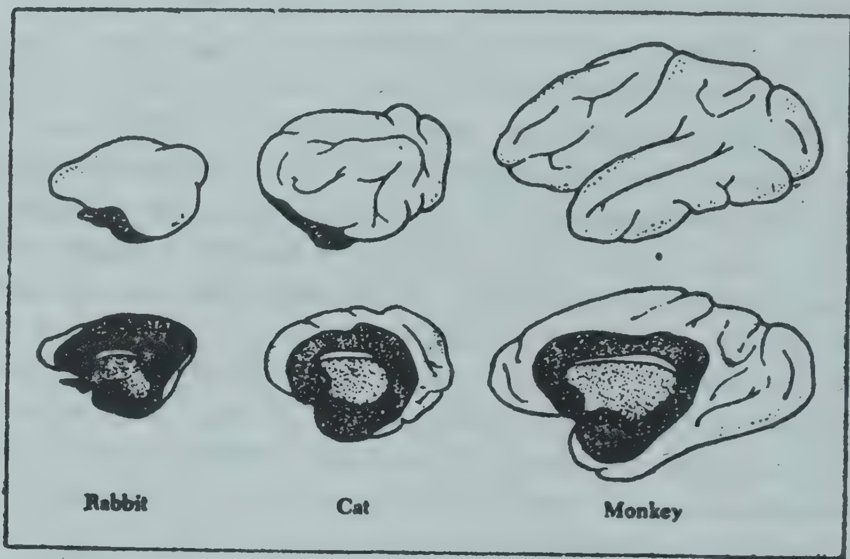


Fig. 53 The relative mass of the brain occupied by the limbic system and neocortex depends upon the degree of evolution of the animal as illustrated here through diagrams of the rabbit, cat and monkey brain. (Reprinted with permission from Sagan, Carl. The Dragons of Eden. 1977. p. 60. Courtesy: Random, House, Inc. New York, U.S.A.).

the brain by the large, furrowed, hemispherical cerebral cortex. The cerebral cortex may be considered the 'thinking cap' of man which bestows on him intelligence and capacity for abstract thought. The connections between the 'thinking cap' and the 'seat of emotions' are limited. That is why, emotions are so unruly and are not always amenable to reason.

The importance of the limbic system in emotions has been brought out largely by experiments on animals. If the cerebral cortex of cats is removed, they appear very angry. They hiss, growl, tend to bite, and unsheath their claws. Thus, even in cats, the cerebral cortex seems to keep emotional expression partly controlled. In another type of classical experiments, Kluver and

Bucy found that on destroying a small portion of the limbic system, ferocious animals like monkey become very docile and friendly. Such animals are kept in some zoological parks where they play with children. A new technique in the study of emo-

Fig. 54 Self-stimulation apparatus. The monkey in the cage has an electrode implanted in its brain. By pressing the lever in the cage, it can complete the circuit, thereby stimulating its own brain. It is but natural that the monkey will feel like pressing the lever repeatedly only if the stimulus makes it happy.
(Reprinted with permission from Guyton, A. C. Textbook of Medical Physiology. 6th Edition, 1981, Fig. 56-4, p. 703. Courtesy: W. B. Saunders Co., Philadelphia, U.S.A.).

tions was introduced by Olds in the 1960s. In this technique, the animal is placed in a cage in which there is a bar (Fig. 54). On pressing the bar, a point in the animal's brain gets electrically stimulated. The animal soon discovers this. If the stimulation is pleasurable, it goes on pressing it repeatedly; sometimes at an incredible rate. Rats have been found to press the bar 5,000–12,000 times per hour, and monkeys even 17,000 times per hour.

However, if the stimulation induces a feeling of pain or terror, the animal consciously avoids pressing it. Thus, the function of different parts of the brain can be mapped in terms of approach or avoidance systems.

Development of emotions

Emotions develop very early in life, though their expression varies. A newborn cries when uncomfortable; and relaxes or gurgles when all is well. His first smiles and frowns appear within 6–8 weeks. By 6 months, he can clearly express delight, fear, and anger. A young child's emotions are intense and uncontrolled. They are expressed in full vigour, but the storm blows over soon and all is forgotten. As we grow older, we learn to restrain and regulate the expression of our emotions, but the feelings often persist longer. The way an emotion is expressed is influenced quite a bit by cultural factors. For instance, the Chinese scratch their ears and cheeks when they are happy.

The early appearance of emotions suggests the possibility of heritability of emotions. Animal experiments have repeatedly and uniformly shown that quantitative aspects of emotions are inherited. For instance, 'fearfulness' in rats as measured by defecation when put in a brightly lit circular enclosure, or 'timidity' in mice as measured by their reluctance to traverse a tunnel, are features which are heritable. Though such experiments are not possible on human beings, it is reasonably certain that the vigour and frequency with which a certain type of situation can evoke an emotional reaction in a human being depends, at least partly, on his inheritance.

Life is composed of pairs of opposites. It has pain and pleasure, joy and sorrow, for everyone. Control of emotions tempers both components of the pairs. It is almost impossible to enjoy too much of ordinary pleasures, but turn into an ascetic when the turn for pain comes.

CHAPTER 15

HUNGER AND THIRST

Does hunger lead to anger ? Does anger suppress hunger while sharpening thirst ? Physiologists are indeed thirsty to know perfect answers to these questions. However, what they do know is that hunger, thirst and anger are all controlled by nearly the same region of the brain, and that being angry makes the mouth dry and stops the movements of the stomach.

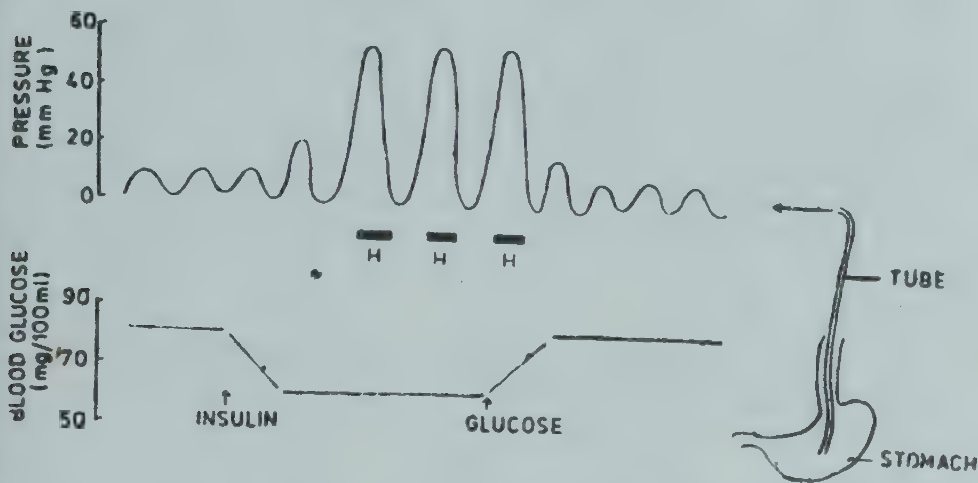


Fig. 55 Hunger pangs are one of the mechanisms by which food intake is matched with requirements. Hunger pangs (H) are felt when the stomach undergoes violent squeezing movements which generate high pressures. Pressure in the stomach may be recorded via a tube. When glucose level in the blood falls, hunger contractions are induced in the stomach, and consequently the person reports hunger pangs. These contractions subside when the glucose level is restored. The blood glucose level may be made to drop rapidly in an experiment by injecting insulin, and it may be restored by injection of glucose.

Hunger is an unpleasant sensation. Though the unpleasant feeling is rather generalized, it appears to originate in the belly.

Correlated with this is the fact that the stomach, which is only one of the organs in the belly, shows strong and frequent contractions during hunger (Fig. 55). Hunger contractions of the stomach have been found to be associated with a fall in the concentration of glucose in the blood, and therefore they can be considered to reflect truly the body's need for food. Further, hunger contractions can be abolished not only by eating food but also by injecting glucose directly into the blood stream. This type of experiments, performed in the early years of the present century by Walter Cannon and his students at the Harvard Medical School, led to the so-called 'peripheral' theory of hunger. According to this theory, hunger originates in the hunger contractions of the sto-

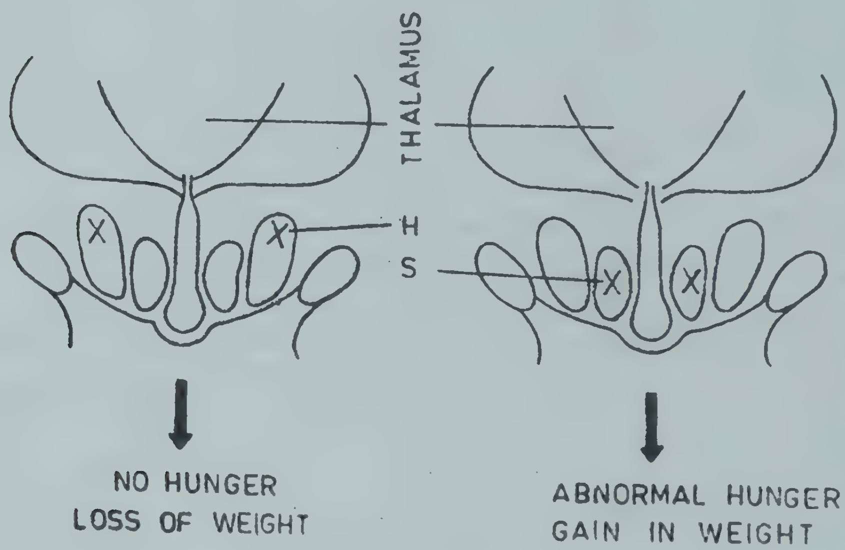


Fig. 56 The hypothalamus is the seat of two opposing mechanisms—one associated with hunger, and another with satiety. The seats of these mechanisms are conventionally called centres. If the hunger centre (H) is experimentally damaged (as indicated by a cross 'X'), the animal loses weight, refuses to touch food, and may starve itself to death. On the other hand, if the satiety centre (S) is damaged, the animal develops a voracious appetite and gets fat.

mach. However, later it was realized that patients who had had their stomach removed surgically also felt hungry. Further, hunger contractions can be abolished even by distending a balloon

in the stomach, but the feeling of hunger cannot be deceived for long by such a manoeuvre. These evidences suggest a deeper mechanism of hunger, of which the hunger contractions are only a superficial manifestation. This mechanism has been discovered to be present in a region at the base of the brain called hypothalamus. The role of hypothalamus in feeding has been investigated very actively for more than three decades. Dr. B. K. Anand and his colleagues at the All India Institute of Medical Sciences made significant contributions to the understanding of hypothalamic mechanisms for hunger. The hypothalamus has been found to be the seat of two opposing mechanisms—one associated with hunger and another with satiety (Fig. 56). The former initiates feeding behaviour, the latter provides the animal a signal to stop eating. The so called 'hunger centre' of the hypothalamus is trigerred into activity by a level of glucose utilization below a well-defined threshold. That is how low concentration of glucose in the blood triggers the hunger centre, and contractions of the stomach as well as other features of feeding behaviour like sniffing and licking (in animals) and hunting the cupboards and fridge (in humans) follow. Ingestion of adequate food shifts the centre of activity from the 'hunger centre' to the 'satiety centre', and the animal stops eating. However, it is important to note that the basic hypothalamic mechanisms are further modulated by other parts of the brain. It is this modulation that makes a person opt for an ice cream though he claims to be full when offered rice. In human beings, routine eating is also a matter of habit rather than a process dependant upon internal cues alone. Psychological, social and sometimes religious considerations gain primary importance in guiding the feeding behaviour of man.

The growth of our knowledge concerning thirst has paralleled that of hunger. Thirst is also an unpleasant feeling—in fact, much more unpleasant than hunger. Just as hunger is associated with strong periodic contractions of the stomach, thirst is accompanied by dryness of the mouth and throat. The dryness is the result of a decrease in the formation of the watery juice (saliva) in the mouth which normally goes on all the time, but becomes particularly marked during eating or even on the sight,

smell or thought of tasty food. During the early years of the present century, attention was focussed on dryness of the mouth as the cause of thirst. But soon it was pointed out that mere wetting of the mouth by rolling water in the mouth does not abolish thirst. On the other hand, even if water is put directly into the stomach without wetting the mouth, thirst disappears. In contrast with the true thirst which results from water deficit, there is also a 'false thirst' which follows prolonged speaking, smoking, or eating of certain foods. False thirst can be satisfied by more wetting of the mouth. It has been found, not very surprisingly though, that the mechanism of true thirst is also localized in the brain, very near the regions signalling hunger and satiety. The so-called 'thirst centre' in the hypothalamus is sensitive to the concentration of salts in blood. In a state of water deficit, blood becomes more concentrated with salts. This activates the thirst centre, resulting in the mouth becoming dry, and the animal hunting for water. Since the body has arrangements for detection of any changes in the salt concentration rather than the total water or salt content of the body, thirst produced by loss of water alone cannot be quenched by drinking salty water. If one drinks salty water, the salt in it is got rid of in the urine by using even more water from the body than was ingested. That is why thirsty mariners cannot drink sea-water when deserted by a ship-wreck. As is the case with hunger, thirst is also modulated by other parts of the brain.

Till recently physiologists were busy studying the mechanisms of hunger and thirst which come into play when a deficiency of food or water develops. However, it is a common observation that animals as well as men seek food and water before any deficit really occurs. They keep furnishing the body with solids as well as fluids periodically in anticipation of a deficit. Recent research by Dr. Gordon Mogenson of the University of Western Ontario, Canada, has revealed that mechanisms for anticipatory eating and drinking are also situated in the brain close to the classical hunger and thirst centres.

It is unfortunate that even today a large majority of humanity experiences the hunger which drives, rather than the appetite which tempts. Hunger and thirst are discomforting sensations

which, if not satisfied in good time, can drive us to 'the utmost endeavour and achievement, or to the depths of despair and degradation'. However, of the two, thirst is more demanding and less easily withstood than hunger. This is understandable because in a well-fed person, the food reserves can last much longer than water reserves.

CHAPTER 16

HEAT AND COLD

The place is Bikaner, time an afternoon of June. There is sand all around, the temperature is 50°C. The skin feels burnt. Put a thermometer in the mouth; it reads 37°C.* Let six months elapse. Try to stand under the starry desert sky. The temperature around is a chilling 5°C, but the thermometer in the mouth still reads 37°C.

This miracle is largely the result of mechanisms that regulate the temperature of the body. The regulation is essential for survival because the various chemical reactions going on in our body get very slow at low temperatures, and stop altogether at temperatures only a little above 40°C. That is one reason why fever causes concern, and high fever can, by itself, kill.

It is important to realise that what the body regulates is the temperature of the blood circulating to various cells of the body. This temperature is more or less equal to the temperature of the interior of the body, also called the core temperature. The temperature on the surface of the body does show fluctuations somewhat parallel to the temperature of the surroundings. That is why the hands feel cold in winters and warm in summers. An idea of the core temperature is usually obtained from the oral or axillary temperature. The axillary temperature is about 0·3°C lower than the mouth temperature.

Regulation of the body temperature depends upon an appropriate balance between factors which tend to raise the temperature, and those which tend to lower the temperature (Fig. 57). Our

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*C stands for centrigrade. The normal body temperature on the Centigrade scale, i.e. 37°C, corresponds to 98·6° on the Fahrenheit (F) scale. The two scales are related by the formula,

$$F = \left(C \times \frac{9}{5}\right) + 32$$

body takes recourse to one set of mechanisms and suppresses the other depending upon the requirements of the situation. One might wonder who tells the body whether sweating or shivering is in the interest of survival.

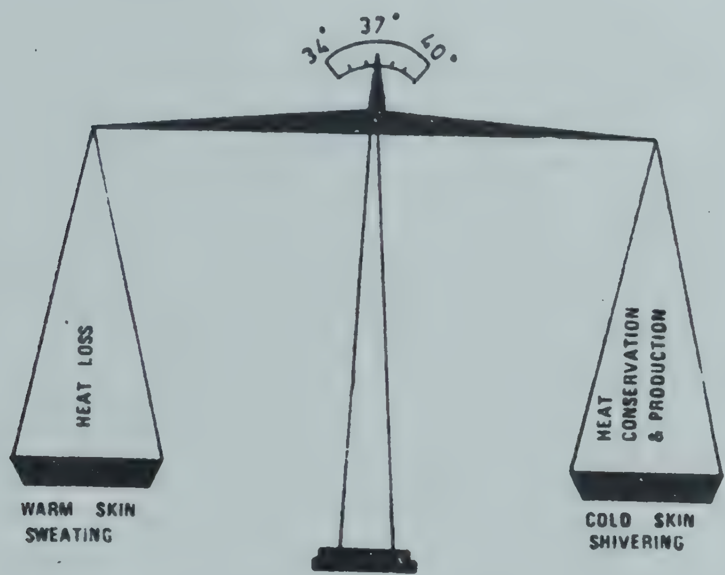

Fig. 57 Body temperature is a product of factors which tend to raise the temperature and those which tend to lower it.

The kingpin of the temperature regulatory mechanism, as in case of many other vital mechanisms, is located in the hypothalamus. The nerve cells in an area of the hypothalamus, called the *preoptic area*, function as heat sensors. A slight rise in the temperature of blood circulating to the area increases the activity of these nerve cells markedly. There is no comparable cold sensor area in the hypothalamus. But the cold receptors of the skin communicate information about low environmental temperature to a region of the hypothalamus behind (posterior to) the preoptic area. Integration of the activity of the preoptic area and the messages flashed to the posterior hypothalamus decides the extent to which mechanisms for raising or lowering body temperature should be activated. These mechanisms, in turn, remove any discrepancy whatsoever between the actual and the desirable body temperature. Removal of the discrepancy also takes away the stimulus for the mechanisms. Thus the system is self-adjusting,

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like the thermostat in an oven. The hypothalamic thermostat is normally set around 37°C.

Facing heat

One can learn a lot from the way a camel faces heat stress. In the desert, it sits facing the sun, and remains sitting on the same spot except for turning its face as the sun moves during the day. Its posture allows only the minimum surface area of its body to be exposed to the sun, a large portion being covered by the shade provided by its long neck. It sits still to avoid sitting on hot ground. These are some of the ways a camel manages to be better adapted to the desert environment than most animals (including man). Another feature which helps the camel (and perhaps to some extent man) in hot surroundings is its large size. Imagine a small and a large object made of the same material lying in the sun for a few minutes. The small object will grow hot while the large one will get just a little warm. Thus a large-sized animal also has the advantage of getting relatively less hot in the sun. That is one reason why children cannot tolerate heat as well as adults. Further, the ship of the desert is also protected by its heavy fur coat, just as man uses clothes for protection against heat. The camel needs water as we do, but it minimizes water loss by passing only 1/4 as much urine as man (taking the weight into consideration), its urine is twice as concentrated as man's, and its stool is very dry. Further, when it gets a chance to drink water, it can drink water from 1/4th to 1/3rd its body weight in one go while a 60 kg man can drink even 1 litre (1/60 th the body weight) with some difficulty. However, contrary to some popular notions, the camel does not store water in the stomach or the hump on its back.

It is evident that man does not have the advantage of as well developed adaptive features as a camel. But man has two advantages which make it possible for him to stand as much and sometimes even more heat than a camel. One is his ability to sweat profusely; the other is his superior intelligence which he has employed to create artificial environments.

Sweating

Man is unique in being the only animal that successfully uses sweating as a means of cooling. Sweating causes cooling by

evaporation. Evaporation of sweat uses heat which is drawn from the body. Sweat is formed by sweat glands which are shaped in the form of a disorderly bunch of string. They open on the surface by means of a long slender tube (Fig. 58).

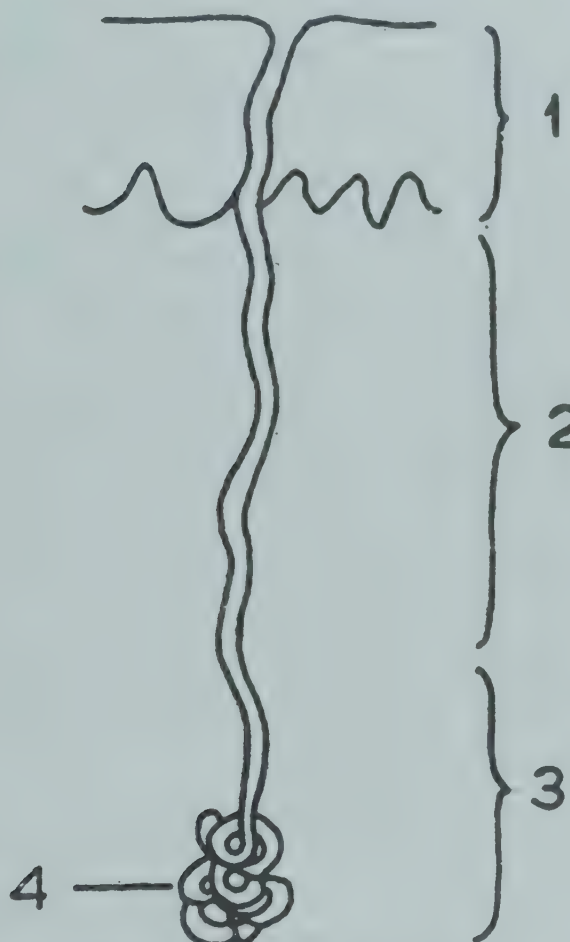

Fig. 58 The sweat glands (4) lie deep under the skin in the subcutaneous tissue (3). Their ducts pierce the dermis (2) and the epidermis (1) to open on the surface of the skin.

Every time the temperature of the blood reaching the hypothalamus exceeds a bit above 37°C, the activity of nerve cells in the preoptic area increases manyfold. That initiates, first, an increase in the blood flow through the skin. Consequently, the skin gets warm and loses heat to the surroundings. The heat so lost helps in restoring the temperature of the blood back to 37°C. However, this mechanism has only a very limited efficacy. During

any significant exposure to heat, sweating is also initiated. In a person accustomed to heat, as much as 1·5 litres of sweat may be produced every hour. But the cooling efficiency of the sweat depends upon its evaporation from the surface of the skin. It is not of much use if it just flows down the skin, as happens in rainy weather; or if it accumulates between the skin and the clothes, as happens with some non-porous synthetic fabrics. That is why heat gets difficult to beat in rainy weather as well as when one is dressed in some synthetic fabrics.

Sweating is useful in cooling the body but it results in loss of considerable amount of water and salt from the body. If the water is replaced but not salt, the limbs start aching (cramps). That cramps are due to salt loss was first shown in 1929 by the famous British scientist, J. S. Haldane, the illustrious father of the illustrious J. B. S. Haldane who spent the evening of his life in India. That is why one should take extra salt, in addition to extra water, during summers.

Further extensive work on heat and water loss was done during the second World War. Dr. Edward Adolph from the University of Rochester, U.S.A., set out with a team of energetic, dedicated young scientists who exposed themselves to extremes of heat and water deficit in the desert areas of California to gather a lot of valuable information on the subject.

Their most interesting conclusion was that using will-power to postpone drinking water neither helps in conserving water, nor does it help in getting better adjusted to heat. Thus water in the stomach is as safe and as useful as in the water bottle, with the difference, however, that only water in the bottle can help a friend who might be more badly in need of water. Adolph and his associates also demonstrated that by trying to tolerate thirst, one cannot get habituated to water deficit. One can get habituated to heat, not to dehydration. Getting used to the heat involves a sharpening and improvement of the normal response. Sweat issues forth at lower temperatures, is more profuse, and contains less salt.

Besides sweating, there are many devices which man has created to face heat better. Appropriate clothing helps to keep radiant heat away from the body. White or light coloured clothes are better in this respect than dark coloured ones. Regarding umbrellas, the

ideal would be one with a white top and a black undersurface, so that it keeps radiant heat from reaching the body, but absorbs readily the radiant heat from the body itself.

Fans move the air, and thereby increase the loss of heat by sweating. Air coolers and air conditioners provide more direct comfort by reducing the temperature itself. Cold drinks also provide temporary relief by gaining heat from the body.

Failure to face heat

There is a limit to which the body can face heat. If the challenge exceeds the capacity of the body, the result could be either what is technically called heat exhaustion or heat pyrexia. *Heat exhaustion* is by far the commoner. It results from too much of dilation of skin blood vessels (in an effort to lose heat) and excessive water loss through sweating (again to lose heat). This combination could result in a reduced blood volume to go round in an expanded vascular bed. The result is low blood pressure, weakness, vertigo, headache, nausea, vomiting and fainting. The onset is usually sudden and the duration of collapse brief. *Heat pyrexia* or heat stroke is generally seen only in elderly individuals with a preexisting chronic disease. The chief distinguishing feature from heat exhaustion is that there is an actual breakdown of heat dissipation mechanisms. As a result, there is no sweating and the body temperature is raised. The victim may at first have symptoms similar to those of heat exhaustion, or may faint straightaway.

Prevention of heat exhaustion and heat pyrexia is best done by taking liberal quantities of salt and water prior to heat exposure. The very young and very old should take special care in hot weather. They should avoid exposure to sun, wear light weight and light coloured clothing, and take frequent cold baths.

Facing cold

While facing cold, man resorts to aids like woollens quite often rather than depend upon the inbuilt mechanisms for temperature regulation. Perhaps the reason is that while heavy clothing provides a portable protection at a reasonable cost, comparable devices for creating a cold environment are beyond the reach of most of us. When exposed to cold, one of the first responses of the body is to reduce the blood flow to the skin. That cools the skin, reducing thereby the loss of heat from the skin to the surround-

ings. If the exposure is even a little more severe, shivering sets in. Shivering increases production of heat in the muscles involved, thereby making it easier to maintain the body temperature. Some more generalized methods for producing heat are also initiated, e.g. release of adrenaline and noradrenaline from the adrenal medulla. These hormones increase the rate of metabolic reactions in the body, thereby liberating more heat. If the exposure continues for a few weeks, the thyroid hormone output also increases, which is even more efficient in producing heat in the body.

In some animals, a very useful reaction to cold is standing of hair on end. That is why sparrows and cats look so fluffy on winter mornings. This response increases the thickness, and hence the efficiency of the fur in conserving heat in the body. Man also has hair, and a weak response of this nature is seen. But man's hair are too short and sparse to be useful for conservation of heat.

The response to heat and cold already discussed are largely the primitive hypothalamic mechanisms. But modern man employs many heating and cooling devices for comfort. When such gadgets are used, the hypothalamic mechanisms are not much required, and hence not mobilized. A rich man staying in a centrally heated and airconditioned house and office, and moving about in a heated and air-conditioned car, seldom has to draw upon the intrinsic mechanisms of the body for coping with heat or cold. Through prolonged disuse, these mechanisms are blunted, and make the individual poorly equipped to face extremes of heat or cold, when such a situation arises.

Failure to face cold

A generalized fall in body temperature (hypothaermia) due to failure to face cold is not commonly seen. Most of the victims are the extremely poor who cannot procure even bare minimum clothing and shelter, and die while sleeping out in the cold. Occasionally elderly individuals, particularly those with a chronic disease, may also have a fall in temperature on prolonged cold exposure. These individuals are very cold and pale, and have very stiff muscles. They need urgent medical attention.

Much commoner than hypothermia are local injuries produced by exposure of a part of the body to extreme cold. Such exposure

may occur in shipwreck survivors or soldiers. Often it is the feet that have to stay for long periods in cold-water or snow with little protection. The damage in these cases may be reversible with *slow* rewarming, or may be irreversible making amputation necessary.

Fever

We usually take normal body temperature for granted unless a feverish feeling indicates otherwise. But it is good to keep in mind that even in good health, the temperature is not absolutely constant. Even at perfect rest, the temperature tends to rise during the day, being the highest towards the evening. Physical activity raises the body temperature at any time of the day, as does an emotional upheaval. Children and weak adults show a greater rise in body temperature following exercise than strong adults. All these facts are good to keep in mind before one labels a temperature higher than 37°C as a sign of illness.

When the rise is, in fact, due to an illness, it is usually called fever. Fever may be looked upon as the result of resetting of the hypothalamic thermostat at a higher level. That helps us in understanding some of the common accompaniments of fever. When the disease process resets the thermostat at a higher level, the normal body temperature of 37°C is interpreted as 'low' by the hypothalamus. To bring it to the new set point, mechanisms for heat production, such as shivering, are initiated. That is why any rapidly rising fever is associated with 'shivering.' When the underlying disease has got cured, the thermostat is reset at 37°C. But the body temperature is still higher than that. Now the thermostat interprets this high temperature as high, and responds as it would in a normal person exposed to heat. That is why, when a person with fever gets all right, he sweats profusely while the temperature falls to normal.

Drugs like aspirin which reduce the body temperature of a person having fever act by resetting the thermostat back to the normal level. However, they do nothing to a thermostat that is already set at the normal level. That is why these drugs do not lower the temperature of a normal person. While these drugs provide some comfort by reducing the temperature, they leave the basic cause of the fever unaffected. Therefore, the relief

provided is deceptive. Further, their repeated use alters the natural picture of the disease process, thereby making the diagnosis more difficult. Last but not least, aspirin-like drugs are far from safe. Minute but multiple bleeding points are universally seen with every dose of aspirin; occasionally the bleeding can be massive. Prolonged and repeated use may precipitate a peptic ulcer, or cause deafness. Hence it is desirable to use these drugs, like almost any other drug, sparingly, if at all.

CHAPTER 17

SLEEP AND DREAMS

We spend one-third of our lives sleeping but we know very little about sleep. Apart from the technical limitations which, till recently, allowed only superficial investigation of sleep, one reason for this surprising fact is that sleep is one of the most difficult and demanding areas of research. The scientist probing the mysteries of sleep has first to deprive himself of sleep. He has to spend nights observing others sleep, spend days trying to study his observations, and then snatch any hours of sleep that he is still left with.

Mechanisms Of Sleep

The present era of physiological research on sleep began in 1935 with the work of the French physiologist, Bremer, who performed some experiments on the cat brain. The brain has a superficial resemblance to a cauliflower in that it consists of a massive flower like growth supported by a short and stout stem (Fig. 59). Bremer noted that when a part of the brain stem was disconnected from the rest of the brain by a cut, the animal appeared sleepy and displayed all the objective features of sleep (Fig. 59) This concept was carried further in 1949 when Magoun and Moruzzi discovered that an animal sent to sleep by Bremer's technique could be woken up by electrical stimulation of the central core of the portion of the brain stem still joined to the rest of the brain. Thus the activity of the central core of the brain stem was considered, crucial to the state of wakefulness. Now, it so happens that normally this crucial region is kept active by a large variety of external stimuli. This goes well with the usual observation that sleep is heralded by darkness, silence and a comfortable temperature and posture; in short, by a reduction in external stimuli. This concept of sleep held the ground for nearly

a decade. Thus sleep was considered a passive process which took over whenever the surroundings failed to provide enough

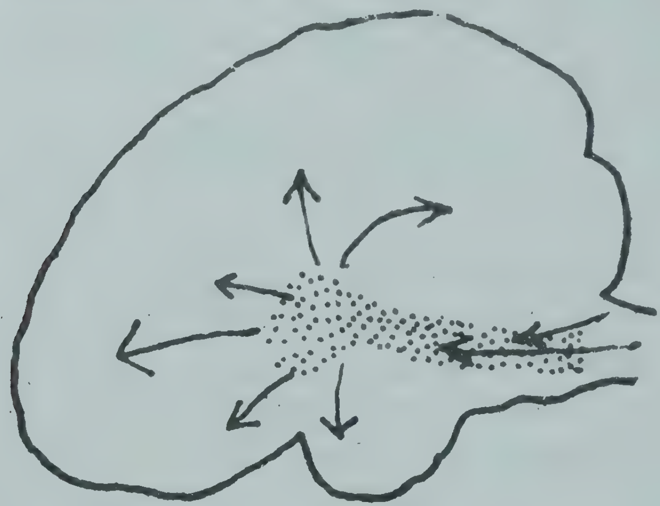

Fig. 59 A large variety of stimuli are conveyed to the brain through the central core of the brain stem (stippled area). Besides conveying specific sensations, these stimuli also keep the brain in a generalised state of arousal, as indicated by the fanning out of the arrows. Interrupting these pathways, as was done in Bremer's experiments, or as normally happens when external stimuli are minimised, induces sleepiness.

(Modified, with permission, from Luciano, DS, Vander AJ, Sherman JH. Human Function and Structure. 1978. Fig. 11-2 B, p. 326. Courtesy. Mc Graw Hill Book Co., New York, U.S.A.).

material to engage attention. However, a little reflection would reveal that this is not the whole truth. Sleep may occur right at the railway station in the midst of loud whistles of the trains, bright lights and shouts of hawkers. On the other hand, one may fail to get even a wink of sleep in the suite of a 5-star hotel if the mind is burdened with worries. Later work has revealed that stimulation of some parts of the brain can bring about sleep. Thus sleep is not merely a passive process depending upon a reduction in the activity of the brain, but rather an integrated phenomenon associated with decreased activity of some and increased activity of some other parts of the brain. As one passes from wakefulness to sleep there is a shift in the pattern of activity of

different parts of the brain. This has been further confirmed by relatively recent work involving a sampling of the activity of single nerve cells of different parts of the brain. Two of the pioneers in this sort of studies are Dr. Evarts of U. S. A. and Dr. T. Desiraju of India. They have mapped many regions of the brain bit by bit and found that there are many patterns of changes in the activity of different nerve cells of the brain. Indeed, some of the nerve cells are very active during sleep. Sleep is thus not a state of perfect rest for the whole body as it superficially appears to be. Some parts of the brain are, in fact, wide awake when the rest of the body sleeps.

Some more recent studies have tried to understand sleep in light of the chemical substances used by nerve cells for communicating with one another (neurotransmitters). One circumscribed region present symmetrically on the right as well as left side of the brain stem, called locus ceruleus, employs adrenaline and related substances as neurotransmitters. Stimulation of this region produces wakefulness, while its selective destruction produces a state resembling sleep. Adrenaline circulating in the blood seems to have a similar effect. That is why, in states of anxiety, which are characterized by high levels of circulating adrenaline, it is difficult to fall asleep. On the other hand, a few patches of nerve cells present in the midline of the brain stem, called raphe nuclei, employ another chemical, serotonin as a neurotransmitter. Stimulation of this region produces sleep, whereas its selective destruction results in wakefulness.

Coming down from brain cells and neurotransmitters to more obvious processes, we find that sleep is accompanied by many changes in body processes. For instance, the heart rate and blood pressure fall, respiration becomes slower but deeper and more regular, and the body temperature falls. Muscles become relaxed, the muscles of the eyelids, face and neck being the first ones to lose their tone. Indeed, drooping eyelids, an expressionless face, and a gradually sagging neck are unmistakable indications of the approaching sweet slumber. Then it is a sudden jerk in the sagging neck which often wakes up the individual falling asleep. If the neck is well supported while falling asleep, as when reading in an easy chair, then it may be the dropping of the book, due to relaxation of hand musceles, which wakes one up.

Phases of sleep

A major breakthrough in our understanding of sleep resulted from the recording of the electrical activity of the brain from the surface of the scalp (electroencephalography, or EEG). EEG during sleep was first recorded by Loomis and his colleagues in

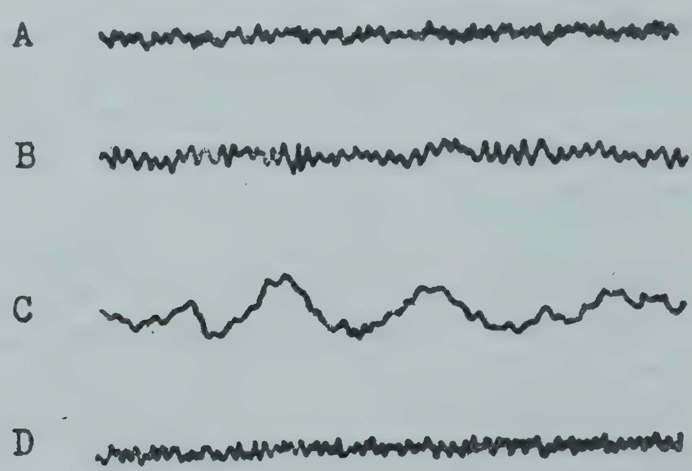

Fig. 60 Typical EEG waves in different states of consciousness.
A. Awake and alert; B. Awake but inattentive; C. Slow wave sleep; D. Fast wave sleep, or dream sleep. Note that the waves in A and D are very similar.
(Modified, with permission, from Luciano DS, Vander AJ, Sherman JH. Human Function and Structure. 1978. Fig. 11-1, p. 324. Courtesy: Mc Graw Hill Book Co., New York, U.S.A.).

1937. They discovered that as the individual fell asleep, the EEG waves became slower and bigger. This finding was confirmed by many but an amazing discovery was made in 1953 when Nathaniel Kleitman and Eugene Aserinsky at Chicago recorded the EEG during sleep for the whole night. They found that the slow and large EEG waves of sleep were cyclically interrupted by fast and small waves, very much like those seen in the awake state (Fig. 60). Observation revealed that during the bouts of fast and small wave EEG, the individual was unmistakably asleep (fast wave sleep); in fact, it was more difficult to arouse him than during the sleep associated with slow and large wave EEG (slow

wave sleep). Other features of periodic fast wave sleep were that the heart beat and breathing were irregular and fast, muscular relaxation was more profound, and the eyeballs displayed rapid to and fro movements. That is why this phase of sleep is sometimes called the rapid eye movement (REM) sleep. Further, if a person is forcibly woken up during REM sleep, he always says that he was dreaming. It is as if the roving eyes follow the panorama of shifting scenes during the dream.

Dreams

Experiments on a large number of subjects all over the world have confirmed the initial findings. Thus, contrary to popular notion, everyone dreams at night. We start with a dreamless (slow wave) sleep, which lasts about an hour and a half. After that there is a bout of dream (fast wave) sleep lasting about 5 min. Thereafter, the two types of sleep keep alternating in a cyclic fashion. Dream sleep occurs, on an average, every 90 minutes. Each bout of dreaming lasts 5–20 minutes, the duration increasing as the morning approaches. As a result, everyone dreams 4-6 times every night. A young adult spends about one-fifth his sleeping time in dream sleep; children spend considerably more. It is merely that we forget most of our dreams. It appears that the only dreams we remember are those during which we wake up.

Thus modern science has now demonstrated three phases of consciousness—wakefulness, sleep and dream sleep. Mandukya Upanishad describes four states of consciousness—waking, dreamless sleep, dreaming and superconscious vision. It is difficult to predict how far science will be able to confirm or refute the existence of the fourth state.

Dreams start and stop on their own without any apparent change in environment. However, change in environment can be incorporated in a dream. For instance, if water is dropped on a person while he is in the REM phase of sleep, there are about 40% chances that he will report falling water as a part of the dream content if woken up as soon as the REM phase is over. Dream content, as is popularly known, usually has some direct or devious connection with our past experiences, present needs and future aspirations. Many feelings which do not find a chance for full expression during wakefulness get a safe outlet in dreams.

That is why Sigmund Freud considered dreams the royal road to the unconscious.

Learning during sleep

Shortcuts to learning are always tempting. The possibility of learning while at the same time enjoying sleep is therefore at once arresting, especially because some brilliant discoveries are reported to have been made in sleep. For instance, it is said that Kekule 'saw' the structure of the benzene ring through a dream in which he saw a snake rolling along with its tail in its mouth, and that brought him the Nobel Prize. Many attempts have been made to learn languages by playing tapes during sleep. However, all such efforts have largely failed. What has, however, been realised is that even during sleep, the brain retains considerable discriminating capacity. For example, the feeble cry of her child can easily wake up a mother, while a much louder sound may fail to do so. Under very specialized training conditions the sleeping brain's capacity to discriminate may be utilized in relation to learning.

Is Sleep Essential ?

Experiments have universally shown impairment of performance and personality changes like depression, apathy and irritability when individuals are deprived of sleep. Such changes are seen even on deprivation lasting only one night, but marked changes are seen only after more than 72 hrs, of continuous sleeplessness. Further, it has been found that both phases of sleep —with & without dreams—are essential. Selective deprivation of one of the phases leads to an increase in the time spent on that phase when allowed to sleep without disturbance. However, the possibility remains that one might be able to make sleep more efficient so that its duration can be reduced somewhat.

Control of sleep

Thousands of prescriptions are written everyday for sleeping pills. Many more cups of tea and coffee are consumed to stay awake and alert. Control of sleep seems to be an important preoccupation of man. While control of sleep through drugs is possible, drugs do have undesirable side effects—a universal one

being dependence. Efforts are going on to control sleep through still safer methods. One such method is induction of electrosleep, which is now about two decades old. In this method, low frequency and low intensity electric current is applied to the head. In most cases, sleep is induced within 20–30 minutes of switching on the unit. Headache is an occasional side effect of the treatment. How exactly it induces sleep is still not well established.

While quite a bit has been learnt about sleep, a lot still remains to be learnt. For instance, we still do not know what determines the cyclicity of the sleep—wakefulness cycle. At the end of about 16 hours of staying awake, what tells the brain to initiate sleep-producing processes is not exactly known. In the same way, we do not know what makes a person awake spontaneously after 8–10 hours of sleep. Why sleep is so essential has also yet to be worked out. The well known physiologist, Arthur Guyton, justifies the necessity for sleep by comparing it to the "rezeroing of a computer", which is required to restore a steady and accurate baseline.

CHAPTER 18

HIGHER FUNCTIONS OF THE BRAIN

Animals experience hunger and thirst just as we do, they sleep and dream the way we do, and they also have feelings of pain and pleasure exactly like us. What distinguishes us from all (other) animals is the quality of the higher functions of our brain. We consider ourselves more intelligent than animals, and at least in some respects this assumption is valid. We still do not understand much about how we learn or remember, and why we behave the way we do. These are areas in which, in the words of Dr. Wilder Penfield, physiologists are "like men who are at the foot of a mountain. They stand in the clearings they have made on the

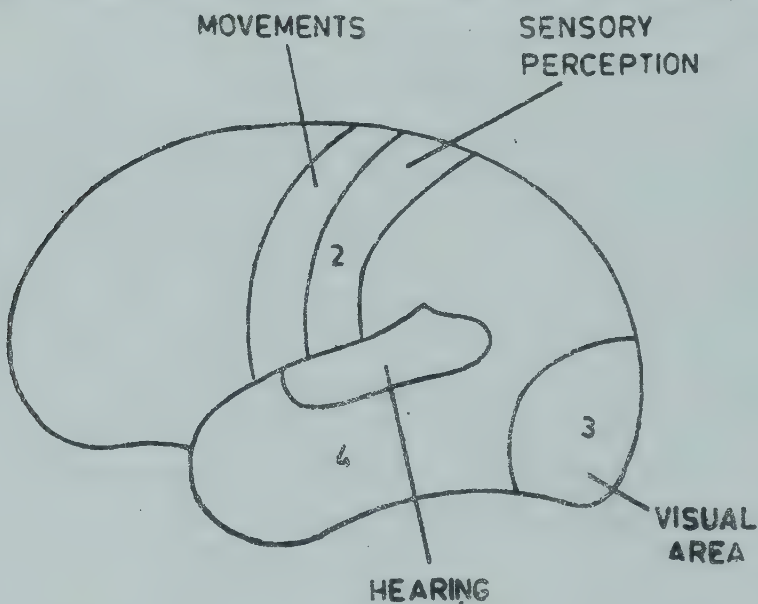

Fig. 61 Lobes and areas of the cerebral cortex. 1, frontal lobe; 2, parietal lobe; 3, occipital lobe; 4, temporal lobe. A few functionally important areas are also indicated.

foothills looking up at the mountain they hope to scale. But the pinnacle is hidden in eternal clouds". In the next few pages, we

will try to get a glimpse of the clearings that have been made.

The highest functions of the brain seem to be organized in the cerebral cortex. This is the wrinkled outer covering that is the most conspicuous part of the brain, which extends in the form of a thin convoluted envelope enclosing the two swollen 'hemispheres' (in fact, quarter spheres). The cerebral cortex deals with all the higher mental functions. It can be further divided into four lobes: the frontal lobe which is important in voluntary movements, the parietal lobe which contains that part of the cortex which receives bodily sensations, the occipital lobe which is important in vision, and the temporal lobe which has the centre for hearing (Fig.61).

Intelligence

Intelligence has long been one of man's universally admired qualities. Every mother wants her child to be 'bright' or 'sharp', and preferably, 'brilliant'. Truly, intelligence, like wealth, is something that everybody feels he could do with more of.

Intelligence is generally measured by the Intelligence Quotient (I.Q.). The concept of I.Q. was first introduced by a French psychologist Alfred Binet (1857-1911). On the basis of everyday observations, Binet postulated that intellectual development is a continuous process, and proceeds along similar lines in all children, but that the rate of development differs in different children. As a corollary it follows that a dull child's mental performance would be similar to that of a normal younger child. For instance an average three year old can copy a circle, at five he can copy a square, and at seven, a diamond. A dull seven year old may be just able to copy a square, but not a diamond. Binet expressed it by saying that the mental age of this seven year old child is five years. From these observations, the I.Q. of this child would be $\frac{5}{7} \times 100 = 71$. On the other hand, there may be a bright youngster who can copy a circle *and* a square, *but not* a diamond, at three. His mental age would again be five, and his I. Q. would be $\frac{5}{3} \times 100 = 167$. Hence the general equation for calculation of I.Q. may be expressed as :

$$\frac{\text{Mental age}}{\text{Chronological age}^{*}} \times 100$$

*Chronological age (*chronos*, time) is the ordinarily expressed age which depends purely on the time elapsed since birth.

Since most of us are neither very dull nor very brilliant, generally the mental age does not differ much from the chronological age. Therefore, the I.Q. is most often close to 100.

Although the above method of finding the I.Q. appears reasonable, it has its fallacies. A brilliant one year old might do what an average child does at two, giving an I.Q. of 200. But as this child grows older this value of 200 will not persist; it is likely to fall although it may stay well above 100 throughout. The procedure breaks down completely when applied to adults. After the age of about twenty, mental age remains constant, while chronological age keeps on increasing remorselessly. This may give rise to a ridiculously low I.Q. of 50 in a perfectly normal forty year old, if the above formula is applied straight away. To get over these difficulties,

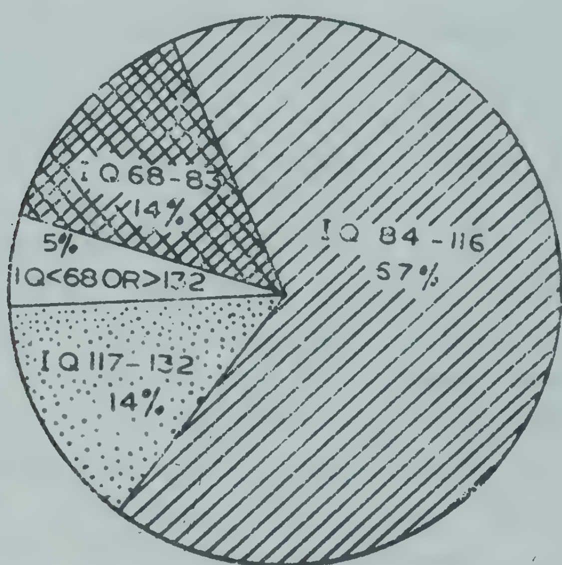

Fig. 62 The frequency of distribution of persons with different intelligence quotients in the human population.

the practice of using the mental age for determining I.Q. has been given up. Instead, the score on an intelligence test is so adjusted statistically that at any age it gives an average I.Q. of 100, and irrespective of age, 95% of the population has an I.Q. between 68 and 132 (Fig. 62). Thus mathematically, the I.Q. is no longer a quotient, though the old name still persists. Since this and various other modifications of Binet's original test were worked out at Stanford University, the present I.Q. test is called the Stanford-Binet test.

The reliability of an I.Q. measurement depends upon the facets of mental ability that have been tested; the more the facets tested, the more reliable the estimate. It is true that a person who is good at one thing is probably also good at another. Thus a person who has a good memory also usually has a good vocabulary and is also good at arithmetic. But this logic should not be carried too far. These associations hold good on *average*, but may not be true for a given individual. Therefore, a truly reliable I.Q. measurement is based on several mental faculties. A properly conducted I.Q. test takes over an hour. It gives a score that is within 5 points of the 'true' I.Q. If the same person were to take such a thorough test several times, even at considerable intervals, the score would remain reasonably constant.

I.Q. measurements are not affected much by the general level of education. Coaching on the actual test items can, however, raise the I.Q. score fallaciously. If special coaching has not been given, suitably designed I.Q. tests provide a satisfactory means of predicting the performance of a given individual in a specific occupation or course of study. This is, in fact, the commonest and most legitimate use of I.Q. tests.

Search for the physical basis of intelligence has not met with much success. It has been natural to look for some features of the brain. An obvious candidate is brain size. The normal adult brain usually weights about 1400 gm, but the range of variation extends from 1100 to 2200 gm. The largest brain on record is that of the English poet, Byron (2200 gm), who was brilliant but perhaps not among the most intelligent men ever born. On the other hand, the brain of Anatole France, dubbed the 20th century Voltaire, weighed only 1100 gm, although he was more intelligent than most people.

Although the brain weight of women is on an average, 150 gm less than that of men, their I.Qs, are equal to those of men. Thus there is no clearcut relationship between the weight of the brain and intelligence. However, a minimum brain mass seems to be necessary for normal intelligence. People with a brain weight under 800 gm are invariably mentally retarded. Another feature of the brain that has been tested in vain as an indicator of intelligence is the complexity and depth of grooves on the surface of the cerebral cortex. In terms of modern neurophysiology, one might

postulate that the number of purposive and well-directed [illegible] connections between neurons, particularly those of the cerebral cortex, might be the determinant of intelligence.

People have always been arguing whether intelligence is inherited or acquired. This is a debate, which is not always conducted in a rational manner. Emotional overtones often cloud known facts. That inheritance is important is shown by the remarkable similarity in the I.Q.s of identical twins, even when they are brought up under different environmental conditions. Children brought up in an institution under almost identical conditions show a wide variation in their I.Q.s, which can only be explained by their heterogenous genetic background. The importance of environmental factors is shown by the changes in I.Q. by 15 points or more after the age of seven when the child is provided highly stimulating, achievement—oriented atmosphere. When one compares the marked correlation of intelligence with genetic material, and the rather limited extent to which environment can alter I.Q., the conclusion is inescapable that heredity is the major determinant of intelligence. It has been calculated that heredity accounts for about three-fourths of intelligence; the environment does play a definite but limited part.

Among the environmental factors that affect mental performance, one that has been widely talked about is nutrition. It has been claimed that poor nutrition impairs the mental function of many a child in countries like ours. While good nutrition is a worthy goal for many scientific, economic, and humanitarian reasons, the intelligence argument is based on rather weak evidence. There are well-documented experiments on animals in which it has been unequivocally shown that malnutrition impairs mental performance. But the degree of malnutrition often produced in these animals is so severe that its counterpart in human societies is virtually non--existent. There are also many studies on human populations where even marginally malnourished populations show a poorer average I.Q. than adequately nourished populations. But in these studies it is impossible to separate the effects of nutrition from those of other environmental factors. Poorly nourished populations also tend to have low parental literacy, poor quality schooling, and a generally unstimulating atmosphere. Therefore, it is impossible to say, to what extent nutrition itself

is responsible for the poorer mental performance. The basis for this highly sceptical approach is that brain is a parasitic organ. It manages to usurp adequate nutrition at the expense of other less vital organs. In a malnourished child, body weight is affected the most, height next, and brain weight the least. That is why he is thin but quite tall, and has a normal-sized head.

I. Q. has come to acquire a mystical quality. Some people tend to look at their I.Q.s, as though they were horoscopes, a low I.Q. forever dooming them to failure. But fortunately, that is not true. A high I.Q. does not guarantee success. Given many qualities which can be acquired, rather than inherited, even a person with only moderate intelligence can be highly successful. A high I.Q. may be a contributory factor to extraordinary creativity and genius, but is not by itself sufficient.

Intelligence does assist in achieving worldly success, and the world has also made significant progress in scientific and technological fields due to the efforts of highly intelligent persons. But many people feel that in the present day world, infested with materialism, epicureanism and consumerism, intelligence is given too much importance. They are perhaps right. Intelligence is not an end in itself. Truth, honesty, compassion and altruism are probably more important for making the world a better place than intelligence. A very noble person may be only moderately intelligent, while a highly intelligent person may be a dangerous criminal. Moreover, intelligence is a gift that is bestowed by nature, while other human qualities are a prize that has to be earned; to be highly intelligent, no hard work is required, but virtues have to be assiduously cultivated.

Learning

A very valuable property of brain, especially the human brain, is its ability to learn. The Nobel Prize winning Russian physiologist, Ivan Pavlov, discovered some fundamental aspects of learning through his famous experiments on dogs. Every dog owner knows how a dog's mouth starts watering as soon as a piece of meat (a 'stimulus') is given to it. This innate response was termed by Pavlov an 'unconditioned reflex'. Now Pavlov rang a bell just before placing meat in front of a dog, and repeated this a number of times (Fig. 63). After a while he found that the dog's mouth

would water as soon as the bell was rung, even when no meat was given. This new response Pavlov called the '*conditioned reflex*'. The dog had *learnt* to associate the ringing of the bell with the piece of meat.

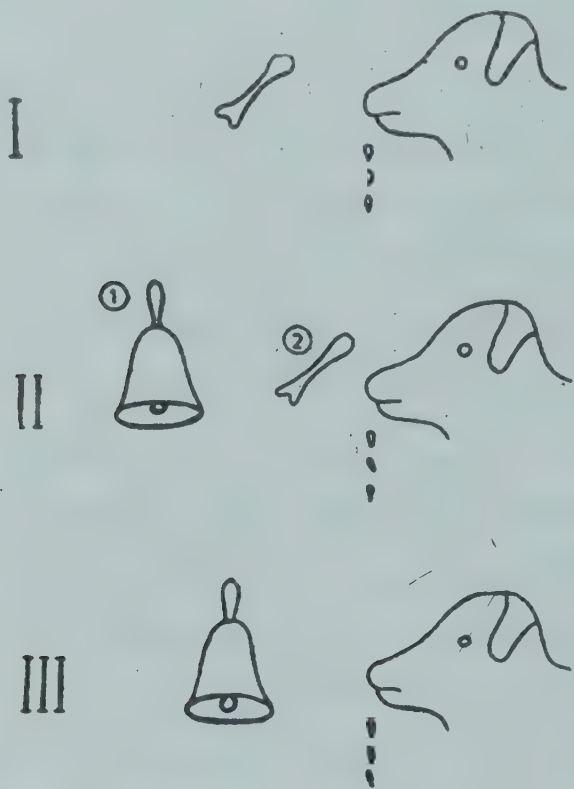

Fig. 63 Conditioned reflex. A bone makes a dog's mouth water (I). If the ringing of a bell (1) precedes the presentation of a bone (2), and the sequence is repeated several times (II), the dog ultimately responds just to the bell by watering of the mouth (III).

Conditioned reflexes form the basis ot almost all types of learning. A little bit of reflection makes one realise that many of the things we do unconsciously are conditioned reflexes learned early in life. No wonder conditioning has provided physiologists with very good animal models to study the process of learning.

In case of the classical experiments of Pavlov, it seems reasonable to suppose that during the process of conditioning, new connections are being developed between the part of the animal's brain that hears the sound of the bell and the part which controls the salivary glands. The potential of the brain to form new

connections is enormous. Each neuron in the cerebral cortex is connected with 1,000–10,000 other neurons.

In Pavlov's experiments, the association of the bell with meat made the dog 'learn' to salivate on listening to the bell. In a variation called *operant conditioning*, pioneered by B. F. Skinner, the animal *learns* to *operate* an 'instrument' to get a reward or to avoid a punishment. The apparatus (Skinner box, Fig. 64) has a lever, which when pressed, delivers a pellet of food. With this apparatus, the animal can be taught to press the lever. The box

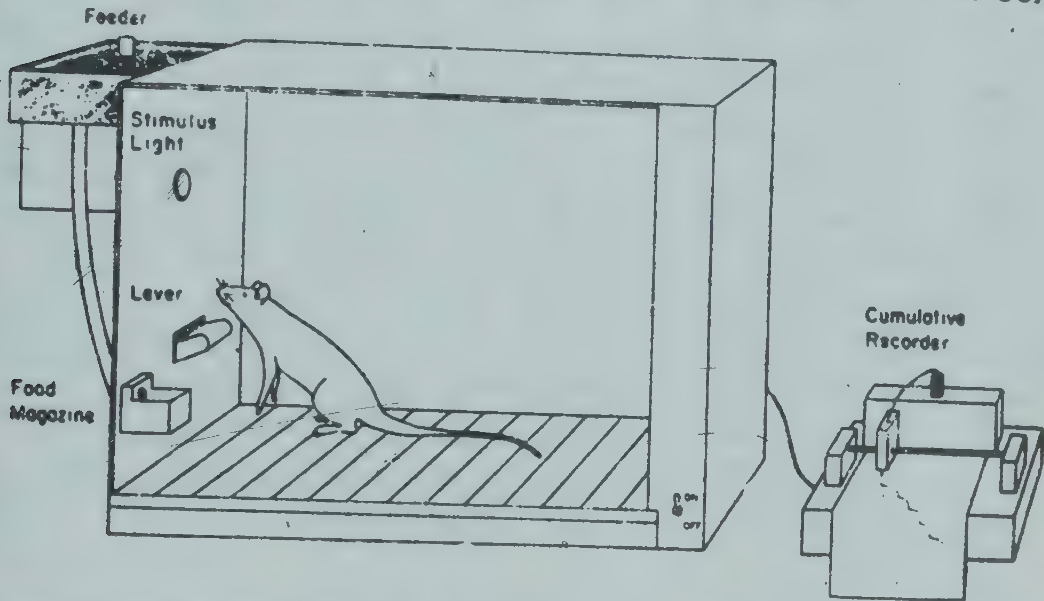

Fig. 64 Skinner box. The box is fitted with a lever which, on pressing, delivers a pellet of food. On the floor of the box is a grid, which may deliver an electric shock. The frequency with which the animal presses the lever gets recorded on the recorder outside the cage. (Reprinted, with permission, from Howell-Fulton: Physiology and Biophysics. Vol. I. The Brain and Neural Function. 20th Edition, 1979. Courtesy: W. B. Saunders Co., Philadelphia, U.S.A.)

may also have a grid which can deliver an electric shock; the animal can then be taught some operation which consistently helps avoid the electric shock. Using the reward–punishment principle, animals can be trained to perform very complex tasks. Some of Skinner's pigeons, for example, learnt to play a crude variety of ping pong. One does not have to look very far to realise that a lot of human learning is also motivated by a reward or avoidance of a punishment.

There is no specific 'seat of learning' anywhere in the brain. On the contrary the whole of the cerebral cortex participates in a

complex way in the process of learning. One very interesting property of the brain is its ability to transfer learning from one of its halves to the other. The two hemispheres have been shown to acquire learning independently, and to communicate it to each other, through a large connection between the two, called the 'corpus callosum'. Very fascinating experiments to investigate this have been performed by the American neurophysiologist Roger Sperry, who received a Nobel Prize in 1981. Sperry cut the corpus callosum of animals such as cats and monkeys, so that the two halves of their brains could not communicate with each other. Such animals are referred to as 'split-brain' animals. He then found that he could teach different things to the two hemispheres of the animals' brains. Thus a split brain monkey could be taught to press a bar with a cross on it, to obtain food with his left hand (connected to the right hemisphere) and to press a bar with a circle on it to obtain food with his right hand (connected to the left hemisphere). The two pieces of learning could coexist in the animals' brains without interfering with each other. In a normal animal, of course, such a thing could not happen. Whatever response is learnt with one hand can also be performed by the other because the learning is transferred from one hemisphere to the other across the intact corpus callosum.

Memory

We look up a number in a telephone directory and remember it long enough to dial it. A few seconds later—if the number isn't very important—we don't have the least idea of the number we had dialled. On the other hand, one day in the market we suddenly come across an old school friend. In a flash, an age old memory revives in our minds, containing minute details like, perhaps, the desk on which he used to sit in the class. The first type of memory is called 'short-term memory'; the second type is known as 'long-term memory'. The importance of this distinction lies not only in the fact that these two perform different functions : the very mechanisms that the brain uses for them are entirely different.

Short-term memory

Short-term memory has a limited capacity—in it we can store

about seven pieces of information. There is evidence that this type of memory is entirely electrical. Nerve impulses keep on going round and round in the brain, retaining the information. Parts of the temporal lobes, which are also involved in hearing, are quite important for this kind of memory. In short-term memory, there is no permanent change in the neural circuits involved. Once the information is used and not required any longer, the impulses cease circulating and the information is forgotten.

Long-term memory

Consolidation of short-term memory into long-term memory requires modification or growth of neuronal connections. It has been found that these modifications require the formation of new proteins. This raises the fascinating possibility that the proteins themselves may store memories by some sort of code. If this is true, then it may be possible to transfer memories from one person to another by transfer of the appropriate proteins. Of course this is very much a fantasy and the consensus of scientific opinion today is that such a thing is unlikely to materialize. The part of the brain that is supremely important in the conversion of short-term memories into long-term ones is called the hippocampus.

Improving memory

Very few people are satisfied with their powers of memory. The best known *drugs* that improve learning in animals are caffeine (present in tea and coffee), nicotine (present in cigarettes) and amphetamine (better known as dexedrine). All these are often consumed by students before examinations. They do not act specifically on memory mechanisms but are general stimulants of the brain. This results in better consolidation of memory. As we know, however, all of these, and especially the last two, can be very harmful so that their beneficial effects on memory have to be balanced against their ill effects. The ill effects are not just physical. Amphetamine causes unjustified euphoria, which may prove dangerous in an examination. The *psychological techniques* to improve memory may yield better results and are much safer. These include review and repetition of learned matter, use of association and mental imagery. All these techni-

ques require patience and practice to cultivate as habits, but they can be really effective. However, there are no short cuts that will miraculously transform memory; it is a slow and painstaking process. The decision that a person must take is whether he is willing to take all the trouble to constantly improve his memory. At this point most people feel tempted to say, "Forget it".

Computers and the brain

In these days of computers, comparing the brain to a computer has almost become a cliche. The role of association in learning is being increasingly appreciated in modern research on Artificial Intelligence. While we are accustomed to treating computers as 'mechanical' and 'incapable of learning', computer programmes are being developed which can exhibit associative learning. Machines called perceptrons have been made, which in principle have wiring patterns similar to those in the brain, viz, circuits that are facilitated when an association is formed. Thus the notion of a learning computer is not an impossibility, though of course such efforts are still in the rudimentary stage. It is likely that the designing of machines capable of imitating the human ability to learn will teach us more about the human brain itself.

However, there will perhaps always remain one fundamental difference between computers and the brain. The computer follows a program, however complex. In other words, it does exactly what it has been taught. The brain comes up with responses which it has never been taught earlier. One may compare the computer to a beginner and the brain to an expert. The beginning driver is taught rules. He does all his driving (or at least tries to!) according to these rules. But as he becomes an expert, he takes in a comprehensive view of the road and his destination, and adjusts his driving without any conscious awareness of the rules. That is why he is even able to break a rule, when doing so would prevent an accident. The computer's superior speed, accuracy, and memory enable it to surpass human beginners using the same rules. But no computer can match an expert who comes up with the most suitable solution for every new problem.

CHAPTER 19

HEARING AND NOISE

Deafness is often not considered a serious handicap. A blind or a lame man often attracts more sympathy and understanding than a deaf person. This is probably because his misery is not associated with obvious disfigurement. If a child is born deaf, he grows dumb as well (unless treated) because in order to learn speaking, he needs to hear. He is thus condemned to a life without proper communication with his fellow beings. The misery of a person who becomes deaf after having lived normally for a few years is no less, specially if the malady comes suddenly. For effective communication, one needs to speak as well as listen. Not being able to listen invites embarassment, misunderstanding, and sometimes ridicule. This tends to make the victim withdraw into his own shell. He gets buried into a pit of loneliness with only nostalgic memories of the past to cherish. The famous composer, Beethoven, became deaf at the age of 28. No doubt, he composed some of his best pieces only after becoming deaf, but, it is a pity that he couldn't hear them himself. He wrote, "O my fellow men who consider me...unfriendly, peevish or even misanthropic, how greatly do you wrong me. For you do not know the secret reason. Why I appear to you to be so. Ever since my childhood my heart and soul have been imbued with tender feelings of goodwill, and I have always been ready to perform even great actions .. .. If at times I decided just to ignore my infirmity, alas, how cruelly was I then driven back by the intensified sad experience of my poor hearing". There are many preventable causes of deafness, e. g. overconsumption of aspirin, lack of iodine in the diet, and some infectious diseases of the middle ear. Now we can add to the list a very important cause which is purely man-made, i.e. noise. In this context, noise means any sound that is physiologically harmful even if the listener finds it pleasant, e.g. "rock"

music, or useful as a source of information, e.g. the sound of some machines.

How we hear

For a proper understanding of how noise harms us, we should

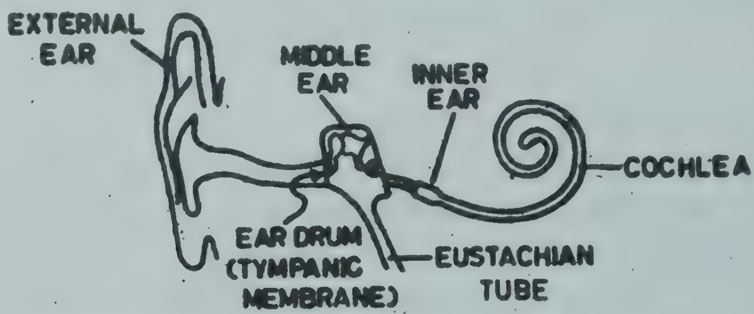

Fig. 65 The external, middle and inner ear.

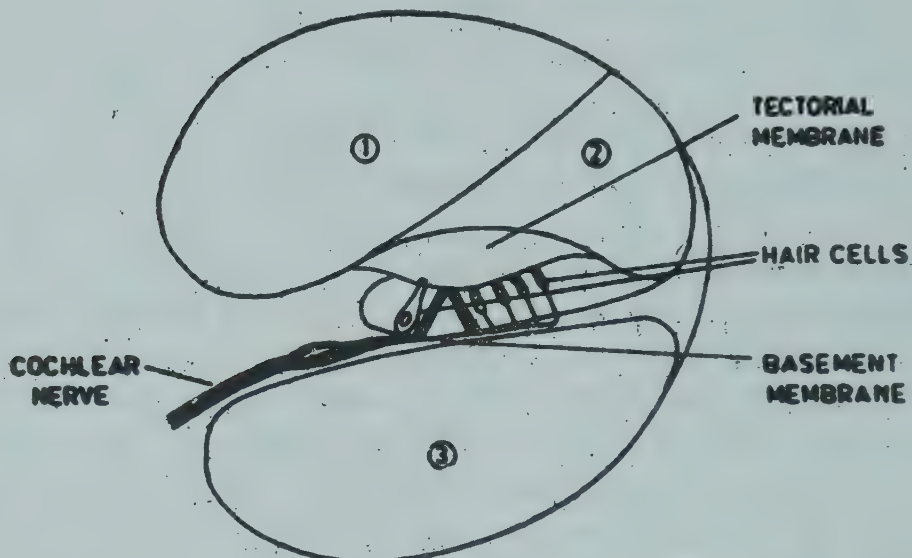

Fig. 66 The inner ear, or cochlea, is a long coiled tube. If it is cut across at any point, it is seen to be divided into three compartments (1, 2 and 3). One of the partitions, the basilar membrane, bears the sensitive hair cells. The hair cells are in contact with the shelf-like tectorial membrane. The fibres of the nerve of hearing (cochlear nerve) originate as processes extending from the hair cells.

know something of how we hear (Fig. 65). The sound waves are funnelled into the ear by the cup-like external ear which we can all see. The waves strike the ear drum and throw it into vibration. The

vibrations of the ear drum are communicated to a system of three minute bones, barely visible to the eye. The bones act like an efficient lever. The last of these bones fits like a piston into the inner ear. Because the area of the piston is only about one-twentieth the area of the ear drum, the pressure (force per unit area) transmitted to the inner ear is about twenty times as much. This is an important service the tiny bones perform because the inner ear is filled with a watery fluid, and it takes much more pressure to produce vibrations in water than in air. The inner ear is snail shaped, and is in fact a long coiled tube. The tube is partitioned into compartments all along its length. (Fig. 66). The major partition, called the basilar membrane, bears along its entire length, millions of neatly arranged cells which have small hair-like outgrowths. As the fluid in the cochlea vibrates, the basilar membrane and consequently the hair cells vibrate. Vibration of hair cells makes the hair rub against a shelf in the inner ear—the tectorial membrane. Rubbing of the hair results in transmission of a message to the brain which makes us aware of the sound. The stiffness and width of the basilar membrane is so graded along its length that different portions of it vibrate in response to sounds of different pitch. That is how we can make out the pitch of a sound.

How noise causes deafness

A machine gets damaged if it is over-used, misused or abused. That holds good for the ear as well. Depending upon the nature of the sound, the external, middle or inner ear can get damaged by noise. Any part of the ear may get damaged by a brief explosive noise like the one produced by fireworks, bomb explosions, or shooting. Here the effect of noise gets compounded by the effect of the blast which can rupture the ear drum, or dislocate the tiny bones of the middle ear. The hair cells of the inner ear can also get damaged by a short explosive noise. In addition, prolonged, non-explosive noises cause subtle damage to the inner ear or neural pathways. The damage is not always visible, even under the microscope. Such noises, which cause slow and progressive hearing loss include vehicular noise, aircraft noise, noise from fans, air-conditioners and generators, noise from radio, television and gramophone records, and noises from factories, especially

those involving reveting, chipping, boiler-making and weaving. That long-term exposure to noise causes deafness has been proved by the high incidence of early deafness in those engaged in occupations which involve exposure to noise. Further, the 'normal' partial deafness of old age has been found to be more severe and of earlier onset in people living in modern industrialized societies than in primitive tribal people living away from factories and automobiles. However, the degree of susceptibility to the effects of noise differs widely from one individual to another.

Other effects of noise

Effects of noise on functions other than hearing are mainly psychological. The susceptibility to these effects varies even more widely from one individual to another than is the case with effects on hearing. Some people find it difficult to sleep in noise, some don't care, while others need some 'noise' (e.g. lullaby) to fall asleep. The effect of noise depends also upon the type of sound. For instance, the loud sound of aircraft or the constant ticking of the clock may not interfere with sleep, but the feeble cry of her infant will at once wake up a mother. During the day time also, sounds produce varying degrees of resentment among individuals. Many of the people staying close to airports or railway stations indeed believe that noise has made their life miserable. Among workers, it has been found that noise impairs performance of many types of jobs. This may be partly because of the interference with communication caused by the noise. Usually it is found that the rate of working is not reduced but there is an increase in the errors committed.

Recognizing the hazards of noise, the British Parliament passed the "Noise Abatement Act" in 1960. In U.S.A., the term "noise pollution" is being increasingly used. In India, a 'Noise Trauma Cell' was set up in 1969 at the All-India Institute of Medical Sciences. Noise levels, very close to or above the level dangerous to hearing, have been found in many industries. Discotheques also cross the safe limits of noise, particularly when they play live rather than recorded music.

Overcoming the ill-effects of noise

The ill-effects of noise can be minimised at many stages. Since

prevention is better than cure, the ideal course would be to silence the source of noise itself. The ideal is not always possible or practicable. Some examples of reducing noise at the source are the silencers fitted to automobiles, oiling of machines, or fitting rubber pads to parts which have to strike each other. When sound cannot be reduced at source, it can be kept at a distance. That is one reason why airports are located at a distance from the centre of the city. However, some houses and hotels, of necessity, have to be close to airports or busy roads. In such cases, a little attention to construction can often minimise noise considerably. The silence which you can provide through modern techniques of construction can be judged from the way a reporter described a new hotel near the London Airport in 'The Observer (London)' of March 15, 1964 :

"That this was effective was proved to me by the eerie sight of a soundless Boeing 707 floating past a double glazed bedroom window, while the Hotel was full of noisy visitors, none of whom I could hear."

In some industries where exposure to noise is inevitable, the number of persons exposed and the duration for which they are exposed can be reduced to a minimum. Further, during the exposure, ear protection should be used.

At least as important as providing protective devices is the education of workers about the value of ear protection through lectures, demonstrations and films. This is very important because it has been found that even when protective devices are provided, the workers just keep them aside. They find it rather 'funny' to use them and often cannot see the harm they do themselves because of the slowness with which the ears go deaf. Last, but not least, the workers exposed to noise should be periodically examined to pick out those who are specially vulnerable so that they can be shifted to alternative jobs. Other workers should also be offered alternative jobs as soon as their hearing starts declining.

The expansion of industry and proliferation of automated transport has given rise to considerable noise, which often reaches dangerous levels. The noise can be reduced significantly if we become conscious of its dangers.

CHAPTER 20

SEEING AND BELIEVING

It is not difficult for even a person blessed with normal vision to appreciate the value of vision. In terms of clarity of vision, as well as in terms of variety of shapes and range of colours perceived, man fares better than most animals. The excellence of the sense of sight has tempted man to rely almost exclusively on it for pursuit of food and safety. This is in contrast to animals who depend a lot more on smell and hearing for these activities. Perhaps through disuse, man has suffered a blunting of other senses, particularly that of smell. It is difficult for a man with his eyes closed to find his way around, and to steer himself safely on the road for even a short distance. In addition, much of our knowledge about the world comes through our eyes. Apart from these necessities, vision is also the means by which we can enjoy and appreciate beauty, colour and brightness of the world.

The process of seeing may be divided into a relatively simple physical process comparable to the formation of image in a photographic camera, and a complex neural process resulting in conscious perception of what is seen. The former takes place in the eyes, and the latter in the brain. The optic nerves provide the link between the two.

The visible part of the eye is only a small part of the eye. Each eye is almost spherical in shape, and is, therefore, called the eyeball (Fig. 67). The ball-shape is maintained by two fluids—aqueous and vitreous humor. The outermost layer of the eyeball is the tough, opaque, white *sclera*. It, however, becomes delicate and transparent over a circular patch in front of the eyeball, and is here called the *cornea*. Transparency of the cornea is essential for light to enter the eyeball, and that is a prerequisite for seeing anything at all. Loss of transparency of cornea is one of the common causes of blindness. This may result from an accidental

injury to the cornea, or from a variety of diseases. One of these diseases, Small pox, has happily been eradicated from the world. Another common disease of the eye, trachoma, if ignored, ultimately leads to corneal opacities in its late stages. The most unfortunate preventable cause of blindness is deficiency of Vitamin A. The deficiency can be prevented if the consumption of just 50 g of green leafy vegetables can be ensured every day. If corneal opacity

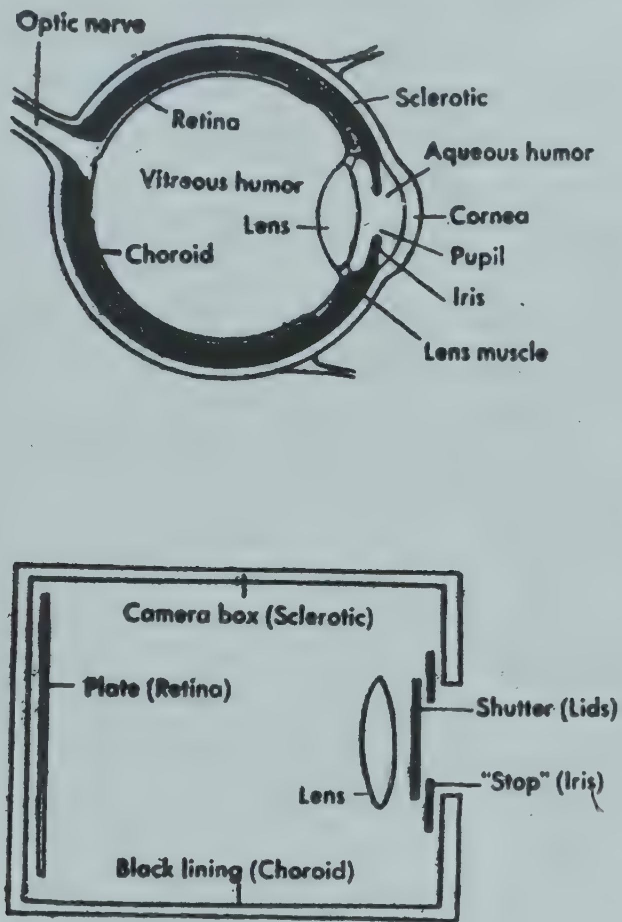

Fig. 67 Diagrammatic representation of the structure of the eyeball. The eye has been compared with a camera in the lower diagram.
(Reprinted with permission from Moon, T. J., Otto, J. H. and Towle, A. Modern Biology. 1963. Fig. 40-9, p. 511. Courtesy: Holt, Rinehart and Winston, Inc. New York, U.S.A.)

is the only defect in the eye, vision can be restored by an operation in which the opaque cornea is replaced by a transparent cornea taken from a donor's eyeball. Fortunately most of us, even after using our eyes for decades, die with healthy corneas, and

therefore have the opportunity of giving a priceless gift to an unknown needy person even after death*.

The layer of the eyeball next to the sclera and cornea is *choroid.* Choroid is richly supplied with blood and contains a coloured substance. Just behind the cornea, the choroid is called the *iris.* The colour of the iris determines the colour of the eyes--it may be black or dark brown, or it may be blue or grey. In a blue or grey iris, there is a distinct pattern of rays, rings and spots. This pattern is highly individualistic, and has been suggested as an alternative to finger prints for identification. The iris is deficient in the centre, leaving a gap of alterable dimensions called the *pupil.* The pupil is the space that admits light. Its diameter in man may range from 1·5 to 8 mm depending, usually, on the intensity of light.

In bright light, it narrows down, reducing the amount of light that may be admitted. In dim light, it is beneficial to admit as much light as possible, hence the pupil opens up. These reflexes take a while to come about. That is why when we enter a dark cinema hall when the movie is running, initally we can't see anything. But, as the pupil dilates, vision improves. Conversely, when we enter the bathroom at night and switch on the light, the glare is unbearable for a short while. But soon the pupils constrict, and we are fairly comfortable again. Besides intensity of light, the distance of the object looked at also affects pupil size. When a near object is being examined, the pupil shrinks to a smaller size. Fear and numerous emotions can enlarge the pupil. Our pupils are circular in shape, irrespective of size. But a cat's pupils are circular only in the dark. In bright light, they narrow down to a fine slit.

The innermost layer of the eyeball is the *retina.* It is the light-sensitive layer comparable to the photographic film. Its sensitivity to light is due to the presence of elongated receptors of two types, called rods and cones, names which roughly indicate their shapes.

The only important structure of the eyeball, that has yet not been mentioned, is the *lens.* It is transparent, has a bulge in the centre, and is elastic in consistency. Its elasticity, and the way it is suspended in the eyeball, makes it possible for the lens to alter the thickness of the central bulge.

*For a list of eye banks in India, see Appendix.

The lens often gets opaque in elderly individuals. The change is gradual, and since its exact causes are still unknown, it might be considered a part of the ageing process. The resulting condition is called cataract. Not enough is known about the causes of cataract to be able to suggest any preventive measures. When cataract has advanced to such an extent as to handicap the individual in carrying out his profession or daily routine, it can be treated by an operation in which the lens is removed. After removal of the lens, the patient is usually given glasses which try to make up for the lost lens. Alternatively, an artificial lens, made of a plastic material, may be implanted during the operation to replace the lost lens. One need not wait for the cataract to mature fully before operating upon it, as has been the traditional concept. With the present day surgical techniques, it is not necessary. After recovery from the operation, an attempt is made to compensate for the lost lens by providing suitable glasses.

The rays of light enter the eye through the cornea, traverse the lens, and strike the retina. The curvature of the cornea and the

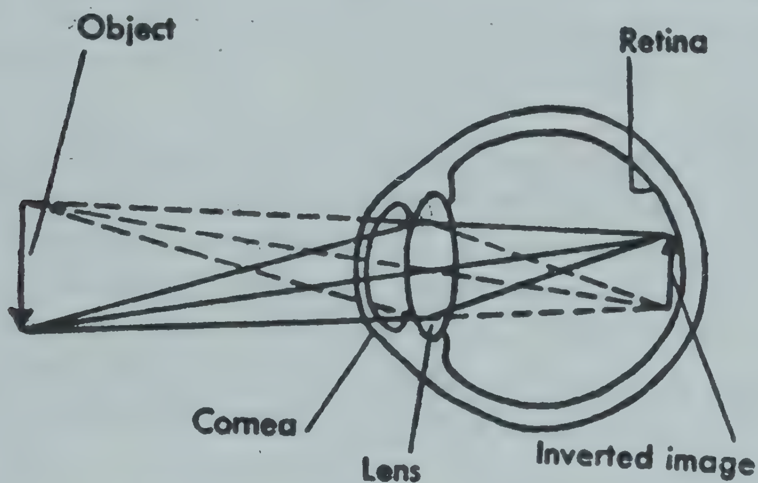

Fig. 68 The formation of image in the eye.
(Reprinted with permission from Moon, T. J., Otto, J. H. and Towle, A. Modern Biology. 1963. Fig. 40-8, p. 510. Courtesy: Holt, Rinehart and Winston, Inc. New York, U.S.A.)

fact that it has air on the outside, and fluid towards the inside, ensure that rays of light bend as shown in Fig. 68 as they pass through the eyeball. As seen in the diagram, the image formed on the retina is upside down. The perceptive processes in the brain

reinvert the image to make it the right way up. The dimensions of the eyeball and lens have to be within a very narrow range to ensure sharpness of the image. Therefore, even relatively minor alterations can result in blurred vision. These defects are called errors of refraction and are the *commonest* disorder of vision. There are three major categories of errors of refraction.

1. Myopia (short sightedness)

This is the common defect in young persons who need glasses. They find it difficult to see distant objects clearly, although they can read a book provided they keep it close enough to the eye. The defect is usually discovered when the child experiences difficulty in reading the blackboard at school.

There is a popular feeling that myopia is getting commoner. This may, at least partly, be due to its more frequent detection, since a large number of children are going to school, and medical check-ups at school are also more frequent now. There is also a popular feeling that the rising incidence is due to nutritional deficiencies, but there is no known nutritional factor associated with myopia. However, what we do know about the cause of myopia is of a strong hereditary factor. That is why it tends to run in families.

In addition, wrong posture and poor lighting conditions while reading might aggravate the tendency to myopia. An encouraging fact for myopes is that myopes are usually quite intelligent. But the converse is not true, i.e. all highly intelligent people are not myopes. It is quite likely that myopes, being handicapped by poor distant vision, might tend to spend more and more time reading rather than playing, thus giving an apparent impression of being 'intelligent'.

From the optics point of view, myopia is the result of refraction that is a bit too strong. Correspondingly, correction involves use of concave lenses (Fig. 69). Such lenses are spherical, and their power is denoted by a negative (minus) sign. They are usually for constant use. Myopic children should get frequent (at least once a year) check-ups because so long as they are growing, their eyes also grow and the dimensions of their eyeball are liable to change. Hence the prescription for their glasses also changes, usually for the worse. However, except in the case of very high myopia

(requiring for correction a lens stronger than-6), there is nothing to worry about. It is rare for the prescription to change after 25 years of age. However, the halt is temporary, and around 40 years of age,

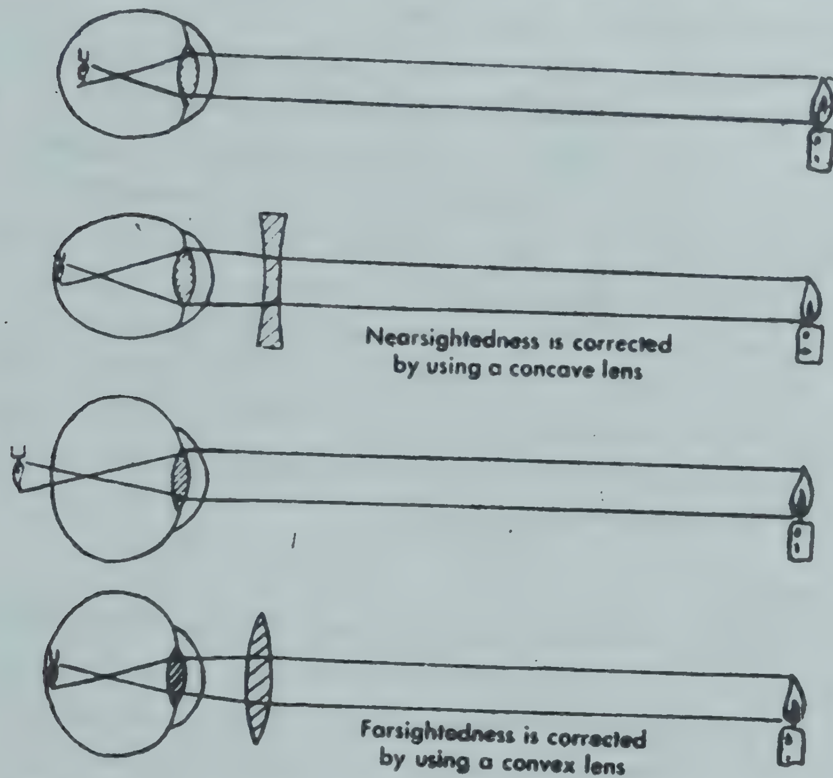

Fig. 69 Common errors of refraction and their correction. In nearsightedness (myopia) the image is formed in front of the retina, and can be made to form exactly on the retina by using a concave lens. In farsightedness (hypermetropia), the image is formed behind the retina (if that were possible), and a sharp image can be made to form on the retina by using a convex lens.
(Reprinted with permission from Moon, T. J., Otto, J. H. and Towle, A. Modern Biology. 1963. Fig. 40-10, p. 512. Courtesy : Holt, Rinehart and Winston, Inc. New York, U. S. A.)

a change is needed again, but for the better. The improvement is illusory since like the rest of the population, myopes also start getting presbyopic (see below) around that age. A mixture of pre-existing myopia and developing presbyopia produces an illusion of improvement, although what it might ultimately lead to is bifocal lenses—a separate lens for each defect.

There are many folk remedies, including walking on dew drops—

early in the morning, for myopia. Whatever other benefits such a walk might confer, its effects on vision have not been proven scientifically.

2. Hypermetropia (long-sightedness)

In this defect, the person is able to see distant objects relatively clearly, but finds it difficult to see the details of near objects. Therefore, he finds reading a strain. Straining while reading might also bring on a headache. In this condition, the power of the lens is insufficient to focus near objects clearly on the retina. A functionally similar defect, called presbyopia, develops almost universally with age, usually after forty. Presbyopia is due to the ageing process which hardens the lens. Thus the lens fails to get thicker (stronger) during reading. Correction of both hypermetropia and presbyopia is by convex lenses, the power of which is denoted by a positive (plus) sign.

3. Astigmatism

In this defect, the horizontal lines may be seen more clearly than the vertical, or vice versa. Astigmatism may be present alone, or in association with other defects of vision. It is usually a minor defect, that does not cause much visual difficulty, but is frequently the cause of headaches. In case of an intractable headache that is present most of the time, it is advisable to get an eye check-up. Paradoxically, it is usually small errors rather than big errors of refraction that cause headaches.

The most familiar device by which eyes are tested for errors of refraction is the Snellen's chart. In this chart the topmost letter can be read by a person with normal vision from a maximum distance of 60 metres, and the last but one line from 6 metres; the lines between them can be read from intermediate distances. The patient is seated at a distance of 6 metres from the chart, and asked to read it from top downwards with one eye at a time. His vision is designated by a fraction, the numerator of which is usually 6, indicating that he is 6 metres away from the chart. The denominator is the distance from which a person with normal vision should be able to read the last line read by the patient. For instance, if the last line that the patient can read from 6 metres is the one that can be read normally from 24 metres, the patient's

vision is designated as 6/24. It must be noted, however, that even an individual who can read the last line might have a significant error of refraction and require glasses.

Binocular vision and squint

Nature has given us two eyes. Many other organs, e.g., lungs and kidneys, are also in pairs, which provides a reserve organ in case one of them is diseased. But in case of eyes, the significance is wider than that. The presence of two eyes broadens our field of vision, and improves perception of depth. Vision based on two eyes is spoken of as binocular vision.

It is a common observation that both eyes move simultaneously and to the same extent when one looks to one side, up or down, without turning the neck. The movement of eyes is produced by muscles attached to the outside of the eyeball. The other end of these muscles is attached to the bony hollow in which the eyeballs are placed. Coordinated function of these muscles is essential for simultaneous perception of the same object by both eyes. If the coordination is impaired, the result may be obvious squint. Squint is not just a cosmetic disfigurement, but may result in only one of the eyes being used for vision. Prolonged disuse of one eye may impair its vision. If not treated in time, the visual loss may be permanent. Such a loss of vision may also result from refusal to use glasses, specially when advised in childhood, particularly when the degree of refractive error in the two eyes is markedly different. Squint and subsequent visual loss may be prevented by getting every child's eyes examined before school age. If, however, the defect is detected, treatment should be sought at the earliest.

Retinal function

So far we have more or less taken for granted the formation of image on the retina. We have already seen that light rays striking the retina stimulate light-sensitive receptors called rods and cones. Rods can perceive even dim light but cannot perceive a colour and do not give a very sharp image. On the other hand cones require bright light to be stimulated, respond differently to different colours, and give a very sharp image. The central portion of the retina has a high density of light receptors, and they are mostly cones, while

the peripheral part of the retina has receptors rather sparsely distributed and they are mostly rods. That is why objects right in front of the eye are seen clearly, while objects lying on one side or a little behind are perceived as a haze. By the same token, in bright light, objects are seen clearly and in their true colours, while in dim light, vision is indistinct and everything puts on a greyish or bluish hue.

The sensitivity of rods and cones to light is due to their containing a substance called visual purple. The visual purple of rods is different from that of cones ; it is further thought (with some evidence) that cones have three different types of visual purple corresponding to the three primary colours—green, blue and red. Each of these three purples is maximally sensitive to only one primary colour. In other words, the colour that we perceive depends on the ratio in which the three types of cones are stimulated. That is quite analogous to making various shades by mixing primary colours in different ratios. Deficiency or absence of one or more types of cone pigments gives rise to various forms of colour weakness or colour blindness. Like haemophilia (*Chapter* 3), colour blindness is also a sex-linked disease which affects only males. Surveys have revealed that about 8% of males are colour blind. Colour blindness is usually partial, and is ordinarily not a serious handicap. In fact, the more common milder forms are little more than an occasional social embarrassment. However, colour blindness precludes employment of the afflicted persons in some occupations like flying or engine driving where accurate perception of colour is of crucial importance.

Chemically, all types of visual purple are a combination of a derivative of vitamin A and a protein. That explains to some extent why one of the earliest symptoms of vitamin A deficiency is delay in dark adaptation. It is common experience that on entering a dark room, such as a cinema hall, for the first few seconds, nothing is visible. But gradually the visibility improves, and everything appears reasonably clear. This change takes much longer and is less complete in vitamin A deficiency. Once the image formed on the retina has been translated into a pattern of stimulation of rods and cones, the information is conveyed to the brain by means of nerve fibres. The first set of nerve fibres originates in the rods and cones themselves. These nerve fibres are carried in

the optic nerves. After a series of relays in neurons, most of the nerve fibres ultimately convey their information to the hind part of cerebral cortex called the visual cortex (Fig. 68). Some crude perception of objects seen may be possible at lower levels, but detailed perception with its attendant interpretation and discrimination takes place only in the cerebral cortex. Quite a few of the optic nerve fibres do not reach the cerebral cortex. They get diverted at lower levels of the brain to form a part of reflex arcs. These reflex arcs are responsible for the visual reflexes. One example of visual reflexes is the involuntary blinking that takes place when a fast approaching object is about to strike the eye; the protective value of the reflex is obvious. Another example is the change in the shape of the lens when we suddenly shift our attention from a distant object to a near one or vice versa. This reflex is called the accommodation reflex, since it 'accommodates' the eye to a change in the location of the target of its attention.

That was a short story of the visual process. The eye is, in a way, a part of the brain that is lodged outside the cranial cavity. To the physician, therefore, the blood vessels of the retina (which can be seen with an ophthalmoscope) provide a conveniently placed view of the state of blood vessels in the brain. The optic nerves provide the physical link between the eyes and the brain. What the eyes 'see' does not make sense till the signals sent by the optic nerves have been processed by the perceptive mechanisms of the visual cortex. We are still at a very elementary stage in our understanding of these mechanisms. What one perceives and appreciates on seeing objects of different forms or shapes partly depends on training, and has a good deal of subjective element in it. Hence the adage that beauty lies in the eyes of the beholder.

APPENDIX

LIST OF EYE BANKS IN INDIA

LOCATION	NAME & ADDRESS OF THE INSTITUTION	
1 ANDHRA PRADESH		
Hyderabad	S. D. Eye Hospital Hyderabad—500 001. (Maintained by Shri. P.M. Kapadia Charitable Trust)	
2. ASSAM		
(i) Silchar	Silchar Medical College, Silchar	
(ii) Gauhati	State Eye Bank Deptt. of Ophthalmology Gauhati Medical College, Gauhati-871001	
3. BIHAR		
(i) Patna	Patna Medical College Patna	
(ii) Ranchi	Rajendra Medical College Ranchi.	
4. CHANDIGARH		
Chandigarh	Eye Bank and Corneal Surgery Unit, Deptt, of Ophthalmology, Post-Graduate Institute of Medical Education & Research Chandigarh—160 012	32351. Ext: 232, 224
5. DELHI		
New Delhi	(i) Guru Nanak Eye Centre, L.N.J.P.N. Hospital, New Delhi—110 002.	268080 275071/330 275071/391
	(ii) National Eye Bank, Dr. R.P. Centre for Ophthalmic Sciences, All India Institute of Medical Sciences New Delhi—110 029	660110
6. GUJARAT		
(i) Ahmedabad	E.D. Anklesaria Central Eye Bank, M & J Instt. of Ophthalmology, New Civil Hospital, Ahmedabad—3.	66391/ Ext. 42
(ii) Baroda	Baroda Citizen Eye Bank, S.S.G. Hospital, Baroda—390 001.	58222
7. HIMACHAL PRADESH		
Simla	H.P. Medical College, Simla—171 001.	2646/26,28 2983 (Res)

8. JAMMU & KASHMIR

(i) Srinagar	Medical College, **Srinagar**.	

9. KERALA

(i) Trivandrum	Medical College, **Trivandrum**	
(ii) Kottayam	Medical College, **Kottayam**.	
(iii) Calicut	Medical College, **Calicut**.	

10. KARNATAKA

(i) Manipal	Kasturba Medical College **Manipal**.	
(ii) Bangalore	Bangalore Medical College, **Bangalore**	
(iii) -do-	Eye Bank, Prabha Eye Clinic, 186, 25th Cross, III Block, Jaya Nagar, **Bangalore**—560011	602334 607699 603479
(iv) Hubli	Karnataka Medical College, **Hubli**.	
(v) Balgaum	J.L.N. Medical College, **Belgaum**.	

11. MADHYA PRADESH

(i) Jabalpur	Eye Bank Govt Medical College, **Jabalpur**.	25851
(ii) Gwalior	G.R Medical College, **Gwalior**.	
(iii) Indore	M.G.M. Medical College, **Indore**.	
(iv) Bhopal	Eye Bank, Hamidia Hospital, **Bhopal**	73364
(v) Raipur	Eye Bank, D.K. Hospital, Eye Department, **Raipur**.	24481 23751

12. MAHARASHTRA

(i) Bombay	Sir J.D. Eye Bank, J.J. Hospital Byculla, **Bombay**—8.	869064
(ii) -do-	Seth G.S. Medical College, **Bombay**.	
(iii) -do-	L.T.M.G. Hospital Eye Bank, **Bombay**.	476381 to 476390
(iv) Pune	Dewan Bhadur S.K. Nayampalli Govt. Eye Bank, Ist Floor Sesstion General Hospitals, Pune.	22221 Extn. 287

(v) Aurangabad	Govt. Medical College, **Aurangabad**	
(vi) Nagpur	Medical College, **Nagpur.**	
13. MANIPUR		
Imphal	Regional Medical College, **Imphal.**	
14. ORISSA		
(i) Cuttack	Guru Nanak Eye Bank, S.C.B. Medical College, **Cuttack.**	
(ii) Berhampur	State Institute of Ophthalmology, M.K.C.G. Medical College, **Berhampur.**	
(ii) Berhampur	State Institute ofOphthalmology, M.K.C.G. Medical College, **Berhampur.**	
(iii) Burla	V.S.S. Medical College, **Burla.**	
15. PONDICHERRY		
Pondicherry	Jawaharlal Instt. of Post-Graduate, Medical Education & Research, **Pondicherry.**	
16. PUNJAB		
(i) Patiala	Government Medical College, **Patiala.**	
(ii) Amritsar	Medical College, **Amritsar.**	
17. RAJASTHAN		
(i) Jaipur	S.M.S. Hospital and Medical College, **Jaipur**—302 004	60291 Extn 312,216, 317
(ii) Udaipur	Eye Bank General Hospital, **Udaipur**—313 001.	3330 3339
(iii) Jodhpur	New Teaching Hospital Eye Bank, Medical College, Shastrinagar, **Jodhpur.**	22513 22933
18. TAMIL NADU		
(i) Madras	Madras Medical College, **Madras.**	
(ii) -do-	Eye Bank, Hirchand Chordia, Eye Hospital, 28, Kandappa Mudali Street, Sowcarpet, **Madras**—600 079.	38274 36367
(iii) Vellore	Christian Medical College, **Vellore**	
(iv) Madurai	Madurai Medical College, **Madurai**	
(v) -do-	Arvind Eye Hospital **Madurai**	

19. UTTAR PRADESH

(i) Agra	S.N. Medical College **Agra**	
(ii) Allahabad	M.K.N. Medical College, **Allahabad.**	
(iii) Aligarh	J.L.N. Medical College, **Aligarh.**	
(iv) Lucknow	K.G. Medical College, **Lucknow.**	

20. WEST BENGAL

(i) Calcutta	Regional Instt. of Ophthalmology, Medical College Hospitals, **Calcutta-700 073**	34-9253 34-4164
(ii) -do-	Atul Eye Bank, Nilratan Sarkar, Medical College Hospital **Calcutta-700014**	24-3213
(iii) -do-	International Eye Bank, 6, Prafulla Sarkar Street, **Calcutta.**	23-8541 (All Night) 481036 341462 332641
(iv) **Bankura**	Bankura Sanmilani Medical College Hospital, **Bankura**	
(v) **Siliguri**	North Bengal Medical College Sushruth Nagar. **Siliguri**	

Information about Eye Bank by courtesy of The Times Eye Research Foundation

CHAPTER 21

TASTE AND SMELL

The association between taste and smell is at least two-fold. First, both sensations arise from stimulation of appropriately sensitive regions by chemical agents. Second, the taste of a food is inextricably mixed up with its smell. In modern man, taste and smell have all but lost their protective function. We do not depend upon these faculties to avoid harmful substances. However. we do long for, and pursue, pleasant tastes and smells as a part of our never-ending search for happiness.

Taste

The sensitive structures (receptors) for taste are located mostly on the tongue. It is said that only dissolved chemicals can be tasted. In practice, however, the tongue itself is moist enough to dissolve anything applied to it, and can therefore taste even a powder. There are four primary tastes—sweet, salty, sour and bitter.

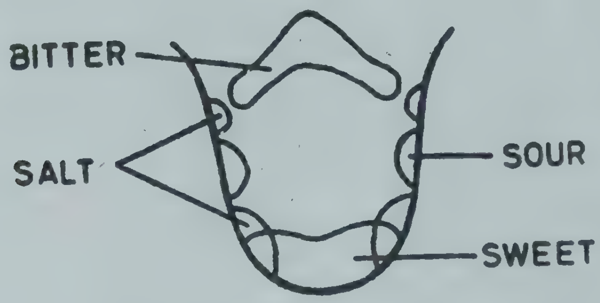

Fig. 70 The distribution of the four primary tastes on the tongue.

The receptors for the four primary tastes are distributed on the tongue roughly as shown in Fig. 70. Although different functionally, the structure of all taste receptors is similar. Under the microscope, they resemble a flower bud, and are hence called taste

buds (Fig. 71). Since the taste buds which can sense sweetness are located close to the tip of the tongue, we instinctively keep sweet things at the tip to taste them. Since the taste buds for bitter taste are situated in the back portion and in the throat, a bitter substance starts tasting bitter only after a while, that is, after it has moved back. For the same reason. if we have to swallow a bitter tablet, we avoid letting it come in contact with the back portion of the tongue or the throat. The process of ageing

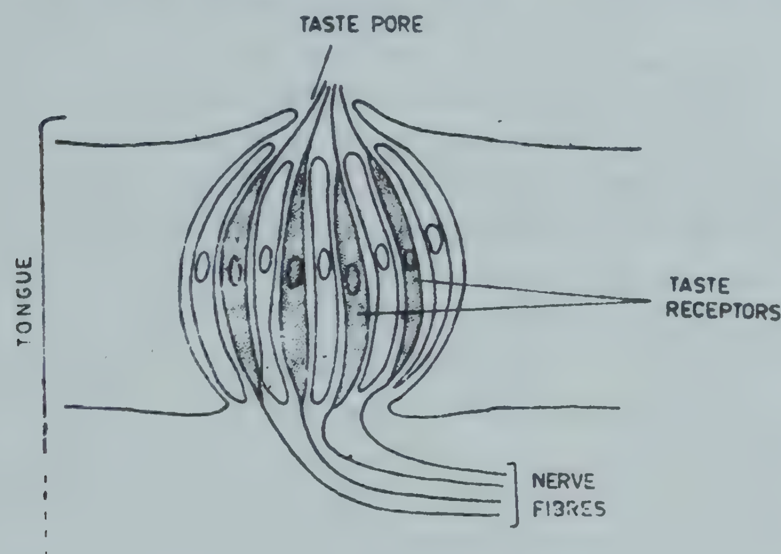

Fig. 71 The structure of a taste bud. Substances placed on the tongue reach the taste receptors via the taste pore.

has a clear destructive effect on the taste buds. Thus the children have many more taste buds than grown-ups. This is one of the reasons why children are usually more concerned with the taste of what they eat. In addition to the four primary tastes, there is also a general sensibility which tells us about the temperature, consistency and texture of food. Further, while a food is being placed in the mouth, it comes pretty close to the nose; and once inside the mouth, it is in continuity with the backside of the nose. The result is that taste gets thoroughly intermingled with smell. The bits of information about the primary taste, temperature, consistency, texture and smell form a perfect blend in our consciousness. Our appreciation of the taste of a food depends upon this integrated information. That is why, when the nose is blocked by a common cold, food does not taste normal. Information from the

tongue and nose is conveyed to the brain, where it is put together, and reaches consciousness.

It is commonly thought that taste is a useful guide to needed nutrients. The impression seems to have originated from ancient medical texts. For instance, Vagbhatta says clearly, "Whatever type of food a person dislikes and whatever he craves for, by avoiding and satisfying these respectively should he correct the excess and paucity respectively of the body constituents". Similar passages occur also in the Charaka and Susruta Samhitas. But clear experimental evidence on the issue is available only for salt. Salt deficient individuals do develop a special liking for salty foods and drinks. For other nutrients, taste can misguide at least as often as guide. For instance, sweets, chillies and fried foods seem to satisfy the palates of many while at the same time harming their bodies.

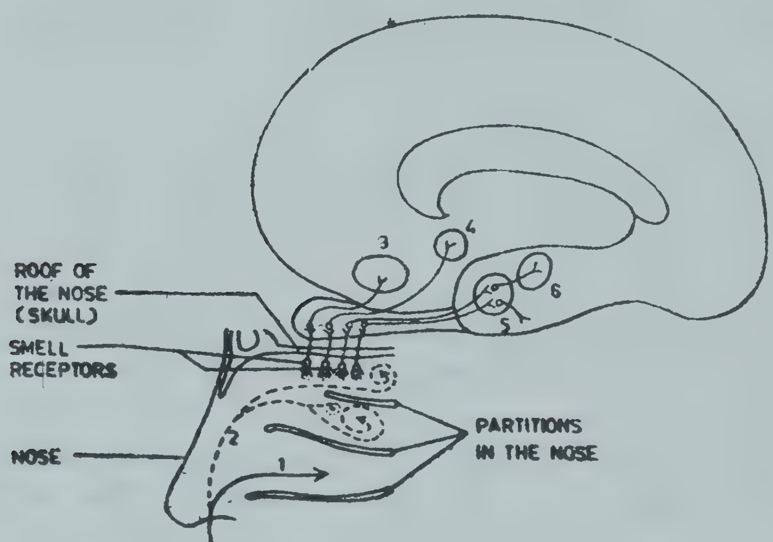

Fig. 72 Smell is picked up by receptors located in the nose. An ordinary quiet breath (1) fails to carry the air to uppermost reaches of the nose where the receptors for smell are placed. A short, sharp breath (2) travels further up, and creates enough turbulence (indicated by spiral arrows) to reach the smell receptors. The message picked up by the receptors is conveyed to specific areas of the brain (3-6).

Smell

Receptors for the sense of smell are situated in the nose. They are most concentrated in the roof of the nose (Fig. 72), so that

they do not lie along the route of an ordinary breath. That is why, we instinctively take a short, sharp breath when we want to smell something. The act, called sniffing, takes the smelly vapours to the uppermost reaches of the nose. When the nose is blocked by a common cold, even sniffing cannot carry the vapours up, and hence it is difficult to smell anything. As a species, man is not very good at detecting smells. However, this statement is purely relative. Man can sort out thousands of smells and can detect the smell of very minute quantities of substances. As such, even a man's smelling abilities are incredible; a dog's over a million times more so. Attempts to identify primary smells along the lines of primary colours and tastes have not been successful.

As in case of other senses, information generated in the receptors in the nose also has to be transmitted to the brain to reach consciousness. The transmission is rather direct, along small nerve twigs that pierce the portion of the skull overlying the nose to join the brain straight away. The areas of brain which receive and help in perception of information about smell are rather widespread. One group of areas is in close relation to the hypothalamus and the rest of the limbic system. The other group of areas occupies substantial regions of the cerebral cortex. The portion of the brain assigned to the olfactory function is relatively small in man, and that accounts for his poorer smelling faculty. Another way to look at it is that man's overall superiority has been achieved in the evolutionary process by reducing the importance of the olfactory function to a reasonable level, thereby sparing more space in the skull for parts of the brain devoted to more advanced intellectual functions.

CHAPTER 22

SEX AND THE CYCLE OF LIFE

Sex is all things to all men, from the most abominable instinct to a source of utmost pleasure. The biological reason for sex lies in the necessity for preservation of the species, or still more broadly, the perpetuation of life on our planet. So strongly has this necessity been felt by nature that it has immensely overloaded us with the sexual desire. While animals satisfy the sex urge in the same way as they satisfy hunger and thirst, man has built around sex a network of social, ethical, religious and legal aspects. At its best, sex is responsible for creative human endeavour. However, the animal in man often overrules his head, making sex responsible for considerable crime and disorder. Although sex involves so many varied angles, the present discussion will be confined to the biological aspects of sex.

The beginning of life

Let us begin from the beginning. Life begins in the mother's womb as a result of the union of two microscopic specks of life—one from the mother, and one from the father—each called a gamete.

Formation of gametes

All animals (and plants), except some very simple ones, are made up of a large number of microscopic units called cells (chapter 2). The cells have a rounded structure called the nucleus, which contains a large number of paired thread-like structures, called chromosomes. In human beings, all cells of the body have 23 pairs of chromosomes (Fig.8). Chromosomes carry the determinants of our bodily features, the genes. 22 pairs of chromosomes in human cells, called autosomes, are alike in men and women. They determine features like the colour of skin, hair or the eyes, the shape of nose or hands, and to some extent

even the personality make-up. The 23rd pair, called the pair of sex chromosomes, consists of two similar members in women, and is designated XX. In men, the two members of the 23rd pair are dissimilar, and it is, therefore, designated XY. Like all parts of the body, *sex organs* also have cells containing 23 pairs of chromosomes. However, within these organs, some cells divide in such a way that they contain only one member of each pair of chromosomes. These cells with only half the quota of chromosomes are called *gametes*. Thus the female gamete contains 22 autosomes and an X chromosome Male gametes are of two types: one containing an X, and another a Y chromosome, besides, of course, the 22 autosomes.

The male gamete

The male gamete, called *sperm*, is formed in the testes (Fig. 73 & 74) The smallest of all human cells, it measures about 0·008 mm. It has a tiny oval head and a whip-like tail about nine times as long.

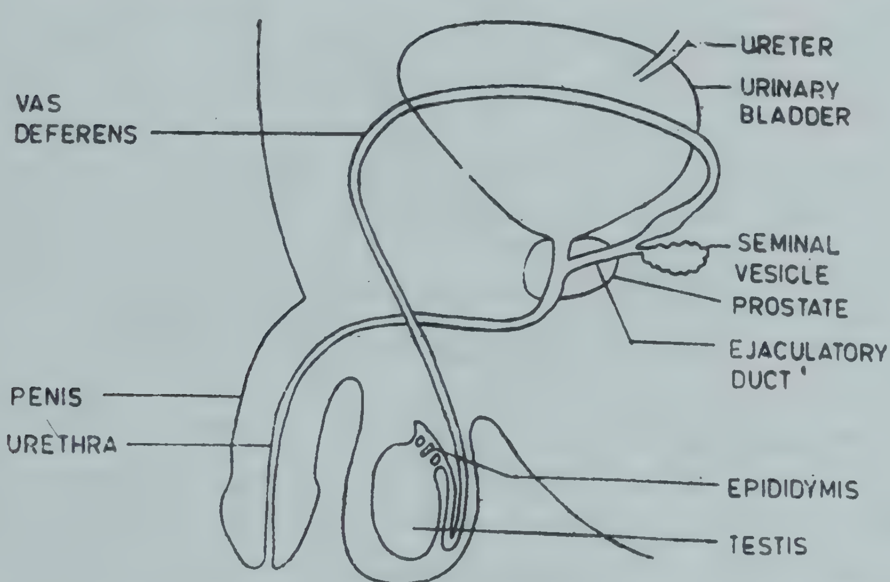

Fig. 73 A diagrammatic representation of the male reproductive system. The connection with the urinary tract is obvious.

It seems to be charged with an unimaginable store of energy, which enables it to swim its way to the ovum. Keeping the sperm's size in view, its 12 cm journey upto the ovum is the equivalent of a man's five-mile swim upstream. The production of sperm is on a much more lavish scale than that of ova. About five hundred million sperm are deposited at a time so that at least one

is likely to find the ovum, if an ovum happens to be available at the moment.

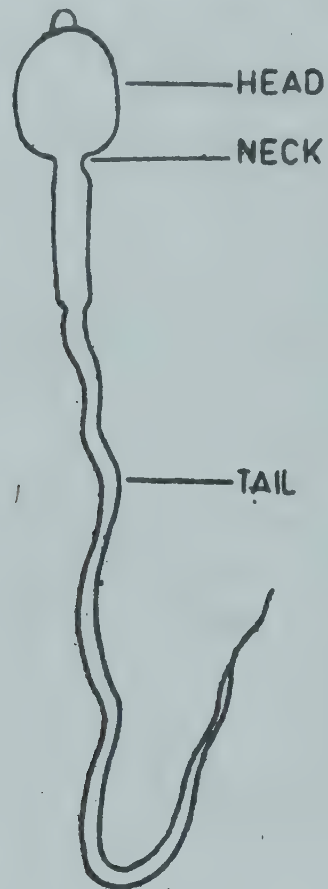

Fig. 74 A sperm, the product of the male reproductive system, highly magnified.

The female gamete

The female gamete is formed in the ovaries (Fig. 75), and is called the *ovum* or egg cell. It is the largest of human cells, and is yet barely visible to the eye, being only 0·13 mm in diameter and 0·000004 g in weight. Usually one mature ovum is shed from the ovary every month during the reproductive age of a woman, which works out to about 400 ova in a life time. Only a few of these unite with the male gamete.

The menstrual cycle

The periodic shedding of the ova by the ovaries is a part of a cycle generated by cyclic fluctuations in sex hormones, and in which the uterus (womb) also participates. Immediately after the

ovum is shed, the uterus starts gets thicker, glandular and more richly supplied with blood. This preparation ensures adequate nou-

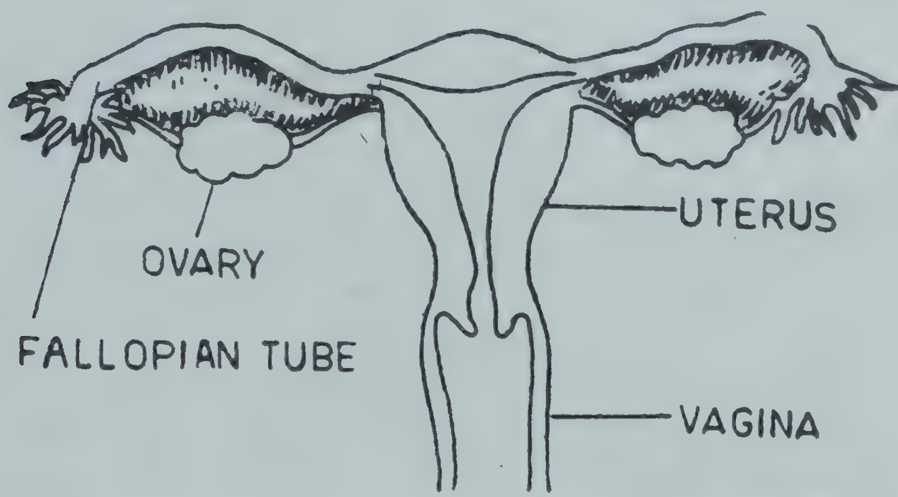

Fig. 75 Diagrammatic representation of the female reproductive system.

rishment and a hospitable environment for the growing embryo, in case the ovum is fertilized (see below). More often than not, however, the 'guest' does not arrive to receive the red carpet welcome. As if to express disappointment, the uterus sheds its inner lining together with a considerable quantity of blood about 2 weeks after the ovum was shed. The 'mourning' (menstruation) goes on for about 4 days. Then the uterus undergoes repair. About 10 days later, another ovum is shed, and like a never-tired host, the uterus starts preparing to receive it all over again. (Fig. 76) The menstrual cycle goes on till the age of about fifty, when ovulation also comes to a halt. This 'change of life' is called *menopause*. Menopause may be accompanied by troublesome flushing of the face and neck, and emotional disturbance. The most important treatment of menopausal symptoms is the realization on the part of the woman that it is normal, and that although she has lost her reproductive ability, she is still worth a lot. Her near and dear ones should also do their best to reassure her that she is still loved, wanted and cared for.

Fertilization

The union of the ovum and sperm is known as fertilization. The cell resulting from fertilization is called the zygote. The zygote contains the full quota of 46 chromosomes. Since half the chromo-

somes have come from the mother and half from the father, the child which develops from the zygote has some features of both.

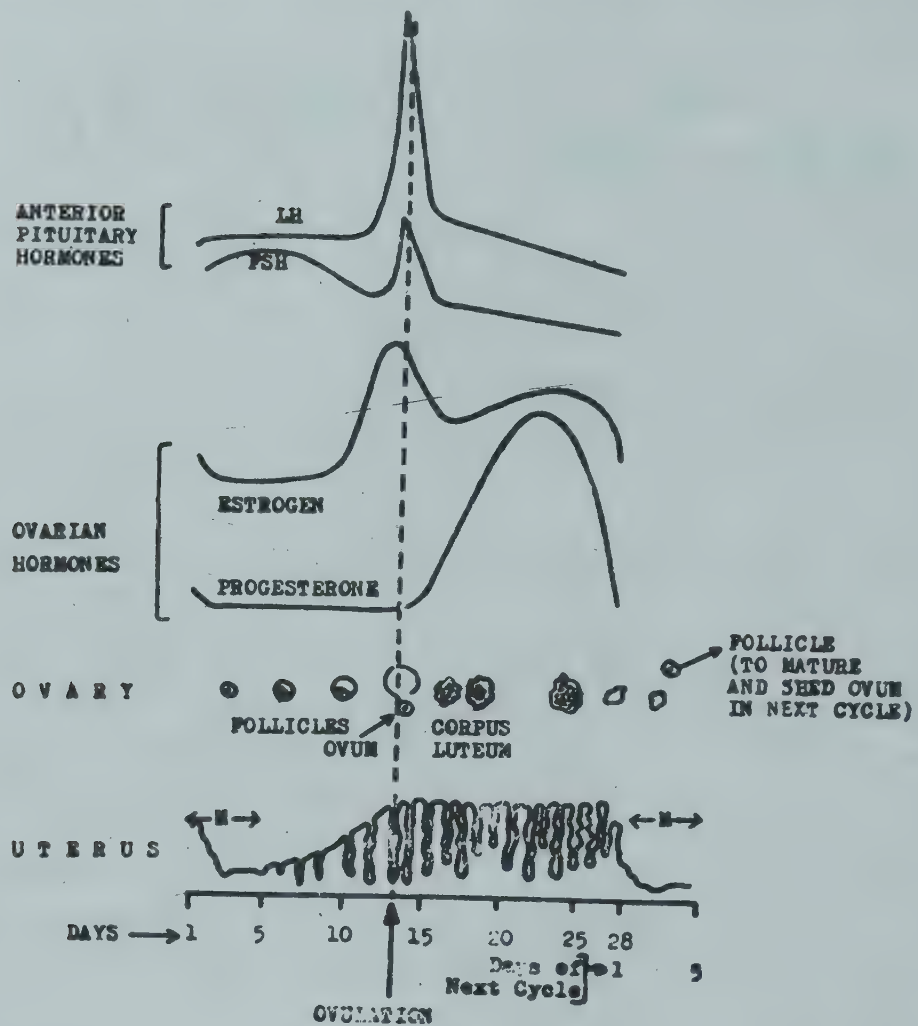

Fig. 76 Hormonal changes during the menstrual cycle, and the accompanying changes in ovary and uterus. The ovum is shed around the middle of the cycle.
LH, luteinizing hormone; FSH, follicle stimulating hormone; M, menstruation.
(Adapted, with permission, from Luciano DS, Vander AJ and Sherman JH. Human Function and Structure. 1978. Fig. 21-13, p. 633. Courtesy : Mc Graw Hill Book Co., New York, U.S.A.)

That is how, through chromosomes, each one of us has at least some bit of characteristics from even the most primitive of our ancestors. The sex of the child to be born also gets determined right at fertilization. The union of the ovum with an X-containing sperm produces an XX type of sex chromosome pattern in the

zygote and therefore results in the development of a female child. On the other hand, if the ovum unites with a Y-containing sperm, the zygote contains the XY type of sex chromatin pattern and there fore, results in the development of a male child. Some of the cells of the child developing in the mother's womb can be obtained from the womb itself and on examining them, the sex of the child can be told in advance. However, nothing can be done to change the sex of the child.

Recently, some differences between X and Y sperm have been described. Based on them, some procedures are being tried experimentally to separate the two types of sperm. Then it might be possible to impregnate the woman with predominantly one type of sperm and increase chances of getting a child of desired sex. While the power to choose the sex of the child might bring happiness to many individuals, for the society at large, it might create problems not hitherto known.

X and Y sperm are produced in approximately equal numbers but the conception ratio of males to females is 160 to 100. Apparently the Y sperm have an advantage in terms of their speed or reaction to environment in the mother's womb. However, at birth the ratio of males to females is reduced to 105 to 100. In later life, the ratio gets levelled off still further, so that in the adult population the numbers of the two sexes are almost equal. This is because the male children are destined to die off at a faster rate at all stages after conception. Thus, male sex is the weaker sex. It is as if nature starts off with a surplus of males to provide for a greater decline in their number later.

The next generation

The child, after birth, appears to be sexually dormant for a few years. Though Freud has suggested sexuality even in infants, the sexual characteristics, as commonly understood, appear in children only at puberty, which appears at about 12-14 years in girls, and about 2 years later in boys. It has shown a tendency to appear at an earlier age in Western countries. The causes in terms of heredity, better nutrition, or late nights are not yet well understood.

At puberty, there is a sudden spurt of growth accompanied by enlargement of breasts, appearance of pubic and axillary hair, and onset of menstruation in girls; and appearance of pubic hair,

beard and moustaches, change in voice, and nocturnal emissions in boys. At puberty, the child is overwhelmed by sudden changes in the body and needs support and guidance to view these changes as normal and healthy. The guidance is essential to provide a feeling of security and adequacy to the young adult so that he or she can face the challenges of adulthood, not all of which are sexual.

What brings about puberty

The immediate cause of changes at puberty are hormones produced by ovaries in females and by the testes in males. The sudden increase in the output of sex hormones at puberty appears to be due to decrease in the sensitivity of the hypothalamo-pituitary axis to feedback inhibition by the sex hormones. As a result, the low childhood levels of sex hormones are no longer able to suppress the hypothalamo-pituitary axis. Consequently, there is an enhanced release of gonadotropin release hormones from the hypothalamus leading to a chain reaction involving increased gonadotropin release and subsequently increased sex hormone release. Sex hormones bring about not only physical changes, but also changes in the mental attitude, and the sex urge. Indeed, the relation between testes and male prowess was speculated by the ancients and a diet containing testicles of a tiger was prescribed for infirmity and impotence in ancient Indian and Chinese systems of medicine. In the modern era, the French physiologist Brown-Sequard was the first to inject himself with extracts from testicles of dogs in a bid to regain his sexual vigour at the age of 72.

The release of hormones from sex organs is controlled by the pituitary gland. The brain also affects sexual functions, directly as well as through the pituitary gland. The primitive regions of the brain, including the hypothalamus, provide the drive for all basic instincts, including sex. They correlate the smell and other sensory information to guide sexual behaviour. Superimposed on these primitive regions in human beings, is the influence of cerebral cortex—the part of the brain involved in intelligence, memory, ideation and abstract thinking. The more developed this control, the better is one's control over basic urges. Extraordinary control of this type can be considered the basis of voluntary abstinence practised by many ascetics. As the French say, there are three sexes—men, women and clergymen.

The cycle comes to a close

After going through the tension and turmoil of puberty, children grow up to be men and women. Their sex organs produce gametes on a lavish scale. When two gametes of opposite sex meet under favourable circumstances, a new cycle of life begins.

CHAPTER 23

CONCEPTION AND CONTRACEPTION

The beginning of life has long been a fascinating area of enquiry, and efforts to understand it have ranged from wild speculation to extensive investigation. One outdated but imaginative concept had it that a miniature person (homunculus) was present in the sperm. But now we know that life begins with the union of a male gamete and a female gamete, that both contribute equally to the genetic information present in the nucleus of the united cell, and that it is the DNA in the nucleus that carries the programme for further growth and differentiation.

The famale gamete, or ovum is formed in the ovaries. Ova are shed at approximately monthly intervals, usually one at a time. The human ovum has 23 chromosomes in its nucleus, and a large store of nourishment in the cytoplasm. Soon after being shed from the ovary, the ovum finds its way into the funnel-like 'hairy' end of the Fallopian tube (Fig. 75). Besides the proximity of the 'funnel' to the ovaries, the currents set up by the 'hair' guide the ovum into the fallopian tube. If a woman has sexual intercourse at a time when an ovum happens to be present in one of her Fallopian tubes, chances are that at least one sperm will swim and make the entire journey from the vagina through the uterus right up to the ovum. The sperm fertilizes the ovum by penetrating it and forms a *zygote*. The human zygote has 46 chromosomes, 23 from the ovum and 23 from the sperm and enough nourishment from the ovum to last till alternative arrangements are made. The zygote continues to move towards the uterus, but simultaneously also starts dividing. It first divides into 2 cells, the 2 cells divide into 4, the 4 cells into 8, and so on. However, the daughter cells get progressively smaller so that by the time the product, now called the embryo, reaches the uterus, it is a compact mass of many cells, but the size of the whole mass is not really much bigger than that of the ovum or the zygote. The uterine wall is in a state of preparedness to receive the

embryo. The embryo creates a shallow hollow in the wall of the uterus, and gets implanted there. Fertilization also triggers appropriate change in the ovaries, so that hormones which had prepared the uterus to receive the embryo are not withdrawn. As a result, the uterus remains thick and well nourished, and there is no menstruation. For the woman, missing a menstrual period is the first indication that she is pregnant. In fact, she had become pregnant two weeks before she missed her period. Menstruation and ovulation stay suspended throughout pregnancy. During this period, a placenta is formed, which provides a link between the maternal and foetal blood circulation. It brings oxygen and nourishment to the foetus, and takes away carbon dioxide and waste products from the foetus. Thus it performs the functions of lungs, intestines as well as kidneys for the foetus. The foetus develops by a twin process of cell division and differentiation. Cell division results in growth, and their differentiation into various shapes and functional units results in the formation of various parts of the body. Pregnancy continues for about 9 months after which the baby is delivered. The expected date of delivery (EDD) is conventionally calculated from the date of the last menstrual period (LMP). Although fertilization, or conception, takes place about 2 wks after the LMP, LMP itself is used for the calculation since that is the date which is precisely known. The EDD is calculated by adding 9 months and 7 days to the LMP. Thus if the LMP is 5th March, the EDD is 12th December. The actual date of delivery usually lies within one week of the EDD on either side. A woman who misses a period has nothing else to indicate that she is pregnant for about a month. Therefore, she cannot be certain about the pregnancy : it could just be delayed periods. If she is curious to find out the true state of affairs, a 'pregnancy test' can be performed on her urine. All pregnancy tests depend upon the fact that the urine of a pregnant woman has an excess of the hormone gonadotropin. The urinary concentration of gonadotropin increases in pregnant women because they manufacture more of the hormone. The excess secretion is the result of an additional source of the hormone during pregnancy. The new source is chorion, one of the precursors of the placenta during early stages of pregnancy. That is why the hormone is also called human chorionic gonadotropin (HCG).

About a month after the missed period, some nausea and occasional vomiting in the mornings (morning sickness) is quite normal and almost universal. Morning sickness continues for at the most about two months, and then vanishes on its own. Besides morning sickness, the only other prominent symptom of early pregnancy is an increase in the frequency of passing urine. This symptom is due to the pressure exerted by the enlarging uterus on the urinary bladder. Paradoxically, the symptom disappears after about 3 months of pregnancy. The relief is provided by the fact that as pregnancy advances, the fattest part of the uterus keeps rising till it rises above the level of the urinary bladder, and is no longer able to press on it. After the first 3 or 4 months of pregnancy, enlargement of the uterus makes its effects obvious on the appearance of the woman. If otherwise prone to constipation or piles, these disorders might be aggravated or precipitated during pregnancy.

During her first pregnancy, a woman is exposed to fantastic promises and dire threats from those around her. She receives multiple instructions regarding dietetic, gymnastic, psychological, and even sartorial discipline. On top of all this are her own imaginary fears. It is well to remember that pregnancy is a normal phenomenon and common sense can be relied upon for guidance. Some simple guidelines on the usual points of enquiry are given below.

1. *Sleep.* A pregnant woman should spend about ten hours out of twenty four in bed. If there is any difficulty in falling asleep, the doctor should be consulted before resorting to sleeping pills. Sleeping pills may affect the baby adversely.

2. *Exercise.* Physical effort should be tailored to suit individual habits. Exertion short of fatigue is the ideal to be aimed at during pregnancy. Strenuous athletic activities should be avoided throughout pregnancy.

3. *Diet.* Harbouring a growing baby makes it necessary for the pregnant woman to eat a little more than in the non-pregnant state. The quantitative increase should be of the order of about 15%.

Qualitatively, the additional diet should be made up of simple

wholesome foods, preferably a judicious mixture of cereals and pulses, some milk and milk products, and some green leafy vegetables. This attention to quality is also important because the growing baby has to form new living matter. If the mother does not eat well during pregnancy, both the mother and the baby suffer. The mother suffers because the baby, like a parasite, draws many of the nutrients from the mother irrespective of their supply. If these nutrients are not being eaten in enough quantity, the mother would get malnourished. The baby suffers because some of the nutrients become available to the baby only if the mother is eating enough of them.

Foods having strong odours, or those leaving an after-taste should be avoided as they may precipitate nausea and vomiting. In view of the tendency to nausea and vomiting, small but frequent meals might be helpful. Water should also be taken often, although a little at a time.

As would be noticed, no special or fad diet is necessary; no major restrictions are advisable either. Simple wholesome foods might be continued with a small increase in quantity and minor adjustments.

4. *Bowel habits*. Constipation is not uncommon during pregnancy. If necessary, some 'Isabgol' might be taken with milk to ensure the passage of soft stool reasonably frequently.

5. *Clothing*. The dress should be comfortable. A woman who has borne a few children already might need a support for the belly.

6. *Breast care*. Beyond usual cleanliness, no special care is necessary. However, if the nipples are retracted, regular manipulation for a few months before delivery might correct the disability by the time the baby comes.

7. *Sex during pregnancy*. During the first few months of pregnancy, sex should be avoided to prevent the risk of an abortion. During the later months of pregnancy, sex should be avoided to prevent introducing disease-producing germs into the mother. During the middle period, there is no important reason for avoiding sex.

8. Drugs. The growing embryo and foetus are much more susceptible to untoward effects of drugs than adults. Therefore, all drugs should be avoided during pregnancy. In any case, a pregnant mother should not take any drug without medical advice.

It is often felt that adequate supply of vitamins and minerals cannot be ensured through diet alone. Therefore, vitamin and mineral pills are routinely prescribed during pregnancy. These pills need not be considered drugs, and should be taken in the prescribed quantity without any apprehension.

End of pregnancy

The onset of labour is marked by frequent, regular and painful contractions of the uterus. The mechanisms that initiate labour are obscure but could possibly include mechanical pressure of the foetus, change in the concentrations of estrogen and progesterone, release of oxytocin from the posterior pituitary, and alteration in the sensitivity of the uterine muscle itself. As a wag once remarked, when the fruit is ripe, it falls. Once labour sets in, it becomes a self-perpetuating process. Uterine contractions initiate a chain of events that lead to more uterine contraction, and so on.

Labour is traditionally divided into three arbitrary stages. The *first stage* extends from the onset of labour pains to full dilatation of the cervix (the lower part of the uterus). At first, the pains are not severe, of about half minute duration, and occur irregularly at intervals of 10 to 30 minutes. The onset of labour is soon followed by a "show", i.e. discharge of a small quantity of blood stained secretion. As labour proceeds, the pains become more frequent and more severe. Towards the end of the first stage, each bout of pain lasts about a minute, and the pains come every three to five minutes. The duration of the first stage varies with the pregnancy. For the first pregnancy, it usually lasts from twelve to twenty four hours, while for subsequent pregnancies it lasts six to eighteen hours. The end of the first stage may coincide with a gush of watery discharge, or the discharge may occur earlier in the first stage or later on in the second stage. The *second stage* of labour extends from full dilatation of the cervix to the delivery of the baby. During the second stage, the pains are more intense and more frequent. Besides, this stage is characterized by voluntary 'bearing-down' efforts on the part of the mother.

The third stage of labour starts after the delivery of the baby and extends till the placenta (after-birth) has been delivered.

Labour is a painful process. It is probably the only painful process in absence of disease. But it is a pain that is promptly and completely healed, quickly forgotten, and accompanied by a reward. The best that a woman can do is not to be tense and apprehensive about it, and to cooperate by making proper bearing down efforts when asked to do so. Such a control, wilfully exercised, reduces the perception of pain. Besides, tension and apprehension prolong labour, and prolonged labour is distressful to the mother as well as the foetus, and also to those attending on them. It is well for the mother to remember that her own mother and millions of other women have gone through this experience before her successfully.

Lactation

The next natural event after delivery is looking after the baby. Nursing forms a very important component of maternal care after delivery, and serves as a partial continuation of the nine-month long organic bond between the mother and child. Physiologically, the very same pituitary hormone (oxytocin) which results in ejection of milk from the breast also brings about a more complete reduction in the size of the uterus by contracting its muscles.

The same pituitary hormone (prolactin) which stimulates synthesis of milk in the breasts also suppresses shedding of ova in the ovary, delaying the birth of the next child, thereby providing a natural spacing mechanism.

Technological progress has, however, disturbed the natural follow-up of pregnancy. This has not been an unmixed blessing. The major drawbacks of cow's or powdered milk are :

1. These feeds being expensive, many families that take to them cannot provide adequate quantities to their children.

2. Poor families living in tropical climates cannot observe the hygiene that should accompany bottle feeding.

3. Recent work has revealed numerous biochemical differences between human breast milk and other milks. The functional significance of some of these differences is known, while that of many others is still unknown. But the extent of differences is so wide that copying human milk may well be given up as a hopeless and

frustrating exercise.

Therefore, there is now a consensus that breast feeding is the most convenient, economical, hygienic and satisfactory method of feeding infants. If the mother embarks on breast feeding with confidence, generally there is enough milk to meet all requirements of the baby for the first six months of life. Thereafter, some supplements might be necessary.

Although it can now be stated on a more scientific footing than ever before that breast milk is the best, one should keep in mind that babies have been successfully fed with the bottle. Therefore, if there is a compelling reason for the mother's inability to breast feed the baby, she need neither feel guilty, nor fear that her baby is doomed to a bleak future.

Contraception (birth control)

The sharp decline in death rate brought about largely by the triumphs of medical science during the last five decades has given rise to a worldwide problem of population explosion. The impact of the double tragedy of population overgrowth and dwindling world resources has been felt most in developing countries. This has led to vigorous thinking about how the birth rate can be brought down. Control of reproduction is important not only from the viewpoint of reducing the frequency of conception but also having pregnancies during convenient phases of life and for having an optimal interval between two pregnancies.

The most fundamental element of reproductive physiology is that sexual congress is essential for conception. This is the basis of the surest method of preventing conception, viz. abstinence. Though there is unanimity on the severe—almost punitive—stress that this method involves, views regarding the rewards it promises are sometimes poles apart. Gandhiji practised abstinence after the age of about forty. Yoga promises great vigour and strength to the man who can retain his 'seed'. On the other hand, abstinence is known to shatter marriages and reduce young people to nervous wrecks. Whatever the consequences of abstinence for an individual may be, it certainly is not the method for an average young couple.

An ancient, probably the earliest, form of birth control practice is the incomplete or interrupted coitus. This reveals further know-

ledge of the reproductive process, i.e. it requires not just sexual union but also ejaculation into the female tract to result in conception. This elementary knowledge together with a little common sense are the basis of a host of age-old contraceptive devices which basically place a barrier between the male organ and the interior of the female passage. The barrier may be purely mechanical, as in the case of condom, diaphragm and cervical cap, or it may be combined with a chemical which damages the spermatozoa, as is done by the application of jellies, creams and pessaries.

Anatomical identification of passages which conduct spermatozoa to the male organ (vas deferens, or simply vas) and ova to the womb (Fallopian tubes) suggested surgical intervention to achieve relatively permanent infertility. This procedure, called sterilization, was initially performed only for eugenic considerations. Some individuals afflicted with mental retardation and other diseases likely to be passed on to their children should not reproduce in the larger interests of society. Now the scope of sterilization has been enlarged to include birth control for carefully considered couples who are unlikely to need another child, at least for a few years. Sterilization is sometimes feared because people feel that the operation would not leave them the same again. These fears are largely unfounded. Mere interruption of passages for sperm or ova does not affect sex desire because the gonads—testes in male and ovaries in female — remain intact. They continue producing their reproductive hormones which get absorbed into the general circulation and produce all their effects in the normal fashion. Further, sterilization, particularly male sterilization, can be reversed by as simple an operation as the one by which it was induced.

Some newer adaptations of male sterilization include a valve in the vas which would give man the power to switch his fertility 'on' or 'off' at will, or deposition of copper in the vas without surgical intervention. These methods however still remain to be perfected.

Man has speculated since ancient days that a woman is not fertile every day, but her fertility is maximum only during certain phases of the menstrual cycle. However, till the 1930s, every book just copied books written earlier and placed the peak fertility of a woman around the menstrual period. No wonder, the method did

not acquire a good reputation. In 1929, Knaus in Austria, and Ogino in Japan, found independently that women shed a single egg from the ovary every month roughly midway between the bleeding episodes of two menstrual cycles (Fig. 76). Correspondingly, the peak fertility would also be midway between two menstrual cycles. Today we know enough facts about the menstrual cycle to make good use of this so called "safe period" or "rhythm" method of birth control.

The shedding of the egg (ovulation) takes place about 14 days before the onset of next menstruation (bleeding). An ovum is fit to be fertilized for about 24 hours after being shed ; and spermatozoa are capable of fertilizing an ovum for a maximum of about 48 hours after being deposited in the vagina. Allowing these periods during which fertilization might take place, the possibility that ovulation might occur 1-2 days earlier or later, and error in the prediction of the next menstruation, as many as 8-10 days in the middle of the cycle become "unsafe". Further the 4-5 days of menstruation itself, though "safe", are not very suitable for intercourse due to hygienic reasons. This takes away about half the cycle, leaving half which is safe and suitable for sexual activity without much risk of conceiving. For educated, intelligent and well adjusted couples, this method is not very difficult to follow and quite safe. The rhythm method is the only metohd, besides total abstinence, which has the approval of the Roman Catholic Church.

If there is one well-established contraceptive which can be considered the outcome of understanding of intricacies of reproductive physiology during the last few decades, it is the 'pill'. The most important ingredient of oral contraceptives is a progestin, a chemical which acts like the normal pregnancy hormone, progesterone. It is common knowledge that ovulation does not occur during pregnancy ; so even under the effect of the pill, the body is fooled into believing that the woman is "pregnant", and therefore ovulation does not occur. Besides inhibiting ovulation, the pill also has effects on egg transport and implantation which make pregnancy unlikely. If taken regularly, these tablets are almost 100% sure to prevent pregnancy.

The major modifications of the 'pill' include various methods designed to deliver small quantities of hormones every day from a

large depot which may be injected once a month or even less frequently than that.

A very recent approach for controlling fertility in males has been the use of antiandrogens. The basis for their use is that maturation of spermatozoa in the epididymis needs much more androgens than are required for libido and other male functions. Thus small quantities of antiandrogens can be used to block effectively the sperm maturation without affecting other male functions. A promising antiandrogen is gossypol, a constituent of unrefined cottonseed oil.

Another set of birth control methods currently under active world-wide investigation is the immunological methods. Just as immunity can be developed to some disease producing germs by using vaccines, attempts are being made to develop immunity against spermatozoa, placenta or some other constituents concerned with pregnancy. One vaccine which has shown considerable promise in the course of animal experiments was developed at the Biochemistry Department of the AIIMS. It is directed against a hormone, human chorionic gonadotropin (HCG), which is formed by the placenta in the pregnant uterus. Immunization against this hormone would nullify the effects of this hormone, and in the absence of this hormone pregnancy cannot continue.

It has been realised that no method of controlling conception is completely certain. Human weaknesses and intrinsic failings of the birth control methods may sometimes result in an unwanted pregnancy. In that case, a couple can now get the pregnancy terminated in a hospital.

After discussing many old and new birth control methods, it may be sobering to think of a method which was used by preliterate people, and is used even today. The intrauterine device, the most popular form of which in India is the Lippes loop, has survived the test of time. But, believe it or not, we still do not know how it acts ! Chances are that it acts at many points. But most investigations so far have shown how the intrauterine device does not act rather than how it acts.

CHAPTER 24

A PEEP INTO THE FUTURE

We stand on the brink of a revolution in biological research. Recent advances in molecular biology enable us to predict the wonders in store for us. Moreover, these wonders are not a part of science fiction, but rather reasonable projections based on what is already possible !

It was barely thirty years ago that Watson and Crick proposed the double helical model of the DNA molecule. This was soon followed by the elucidation of the mechanism by which DNA guides protein synthesis and transmits characters from generation to generation. Now we have taken a major step forwards. It is possible to fragment the DNA of a cell and introduce one of the resulting pieces into another cell. This is what has been called the recombinant DNA technology. Recombination of DNA takes place regularly when a sperm unites with an ovum. But what experimental recombinant DNA technology has made possible is rather unrestricted in scope. A piece of mouse DNA may be incorporated into the DNA of a bacterium. The result of this manipulation would be that the bacterium would start manufacturing the mouse protein coded by the piece of DNA transferred. Not only that, during multiplication the bacterium would duplicate mouse DNA as well. The result could be a colony of 100 billion bacteria capable of synthesizing the mouse protein after just overnight incubation.

The implications of this apparently, and actually, simple technique are enormous. It has already been jumped at by transnational corporations for commercial exploitation, and has also become the centre of a protracted, profound and emotional debate. A few examples would best illustrate the actual and potential applications of genetic engineering, as such manipulations have been called from a broader angle.

Diabetes is a common disease resulting from effective insulin deficiency. The treatment of the disease with insulin injections involves slaughter of millions of animals, and further, injection of animal insulin into man sometimes results in undesirable effects. If the DNA segment coding for insulin synthesis could be taken from a few human cells and incorporated into a living and dividing bacterium, all the daughter cells of the bacterium are likely to synthesize insulin. This insulin would be human insulin. Its injection would not carry the undesirable features of currently available insulin.

The same technique could also be usea to manufacture large quantities of interferon, an antiviral substance produced in man and many animals. The ulility of this interferon is, however, doubtful because it is quite likely that diseases are caused only by those viruses which are not susceptible to interferon. But it is possible that interferon might help individuals who get repeated viral infections due to their inability to mobilize enough of effective endogenous interferon.

Bacterial cells are convenient to use in recombinant DNA technology primarily because they divide rapidly, and can, therefore, produce a large colony in a short period. A large enough colony can act as a factory for manufacturing a protein product. But some bacteria may be potentially capable of producing disease. For instance, *Escherichia coli*, the bacterium commonly used in these experiments, although a 'normal' inhabitant of human intestines, is also capable of producing diarrhea in children or urinary infection in women. Were some such bacteria to escape into the atmosphere from the factories using them for insulin or interferon synthesis, they could pose a unique problem of environmental pollution. Unlike chemical pollutants, bacteria are self-replicating, and it could become a real challenge to contain them. These considerations have led to formulation of safety regulations in many countries. They have also stimulated the growth of the 'hybridoma' technique. This technique makes use of the fact that tumour (or cancer) cells are also capable of rapid proliferation quite like bacterial cells. If the gene (DNA segment) for making human insulin could be incorporated in the nucleus of a tumour cell without impairing its capacity for proliferation, we would have a veritable factory for insulin production without the hazards

associated with bacteria. Hybridoma technique is a successful and well-tried procedure now. Alternatively, in what appears to be the most "futuristic" aspect of this new field, the chemical producing organelles within the cells can be isolated and fixed on a substrate so that they do their job as just another part of the industrial machinery.

The recent perfection of test tube baby technique by Edwards and Steptoe has opened up many far reaching possibilities for genetic engineering. The test tube baby technique consists of fertilization in a laboratory 'test tube' rather than a woman's fallopian tube. The fertilized egg (zygote) is allowed to grow for some time in the test tube. Then the tiny embryo is artificially implanted in a woman's uterus. It is the availability of a human zygote and early embryo in the laboratory that is 'dangerous'. Its genetic material could be tampered with before implantation. The genetic change so produced would get replicated in all or almost all cells of the growing embryo. Finally, the changes would be present also in the gonads of the individual so born. Hence the changes would be transmitted also to subsequent generations through gametes. The introduction of irreversible and inheritable new characters presents many ethical problems.

Genetic engineering techniques have led to many interesting attempts at treatment of inherited diseases. For instance many disorders of the blood are due to an alteration in the type of haemoglobin present in red blood cells. Efforts are going on to take out precursors of red blood cells from the bone marrow, introduce the gene for normal haemoglobin synthesis in these cells, and transplant them back in the bone marrow. It is then expected that the precursors equipped with the new gene would multiply their tribe and generate a stock of normal primitive red cells which could keep supplying normal red blood cells for circulation almost indefinitely.

The applications of genetic engineering extend beyond the realm of biology. Selected and genetically manipulated yeasts and bacteria are likely to be produced in the near future to manufacture for us cooking gas, cheap alcohol (which could partly replace petrol), fertilizers and a vast variety of other chemical substances.

Genetic engineering forms a significant part of the leading edge of biological research today. Its progress has not been as rapid as

it could have possibly been due to the checks imposed on it. The legal restraints have resulted largely from the efforts of enlightened and well-meaning citizens who have felt concerned about a "Brave New World"-like spectre. Like all powerful tools, the use of genetic engineering for human welfare without creating social, moral or environmental hazards ultimately depends upon the sense of responsibility of those handling it.

The National Academy of Sciences of U.S.A. put the problem in the proper perspective in one of its reports in 1980 when it said: "Still other types of new biological understanding raise fears that deeper insights into nature might imperil a just and decent society. But human curiosity cannot be extinguished, nor can the scientific method be unlearned. Someone will learn, somewhere, sometime. Moreover, the reaction will be there, whether or not scientists are permitted to find them; and if we build social policies on false assumptions that contradict reality, we will be building on a crumbling foundation. A democratic and open society, therefore, has no choice but to defend freedom of inquiry, just as it defends freedom of expression". One can only hope that the scientists and industrial corporations holding the key to future applications of latest achievements of biological research will consider the future of mankind more important than short-term gains.

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Written lucidly, this book provides correct knowledge to a layman about the complex human organism. The functions of different parts of the body have been explained with special reference to the deviations in normal function which we call disease. The book is well illustrated with simple and ingeniously designed diagrams.

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